CCD Images & the RRT

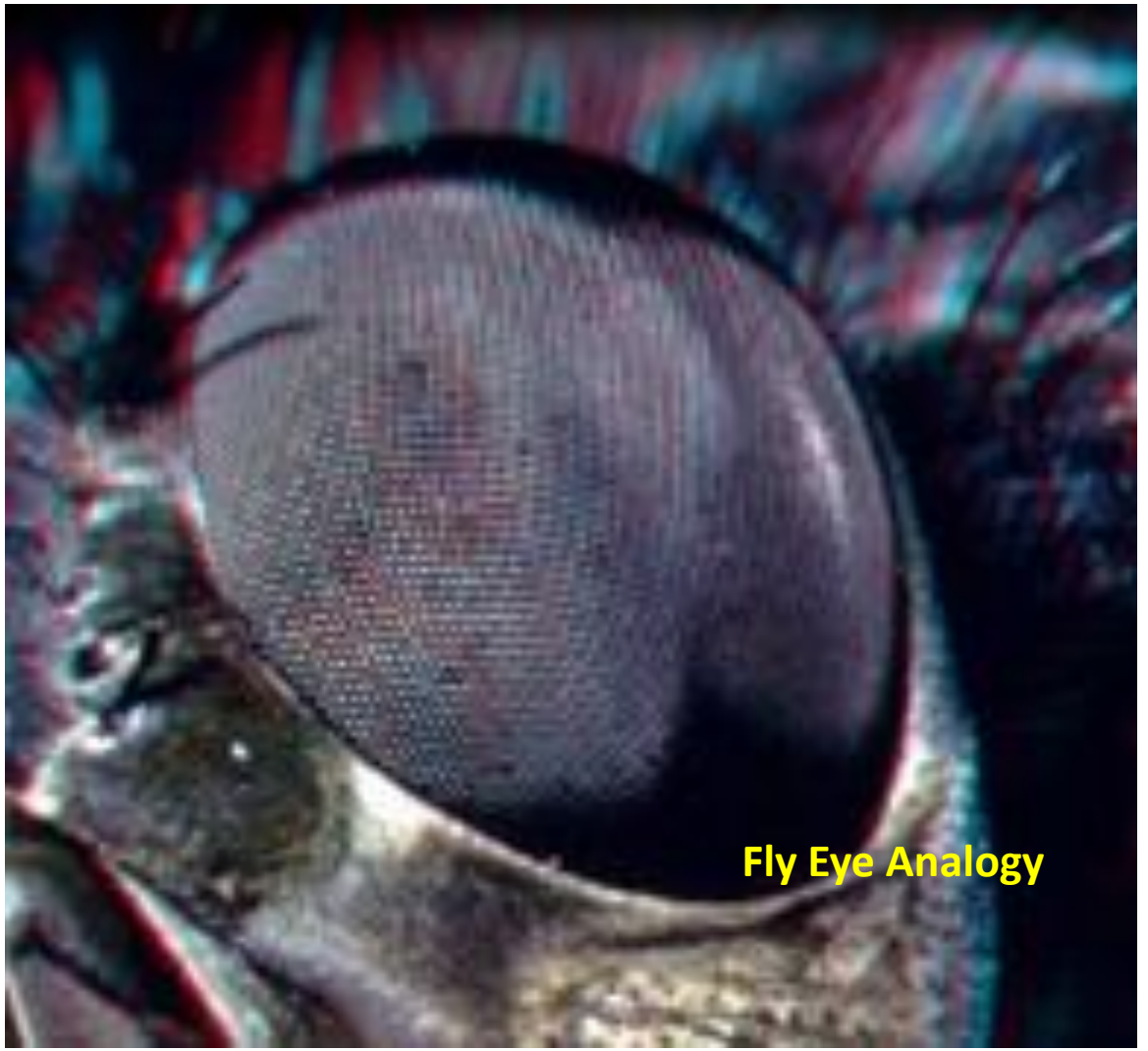
CCD Imaging Comparison (CCDs are/were the BOMB!)

The CCD Light Bucket

- Incoming photons strike the silicon material within a single pixel of a CCD pixel array. (Pixel = picture element)

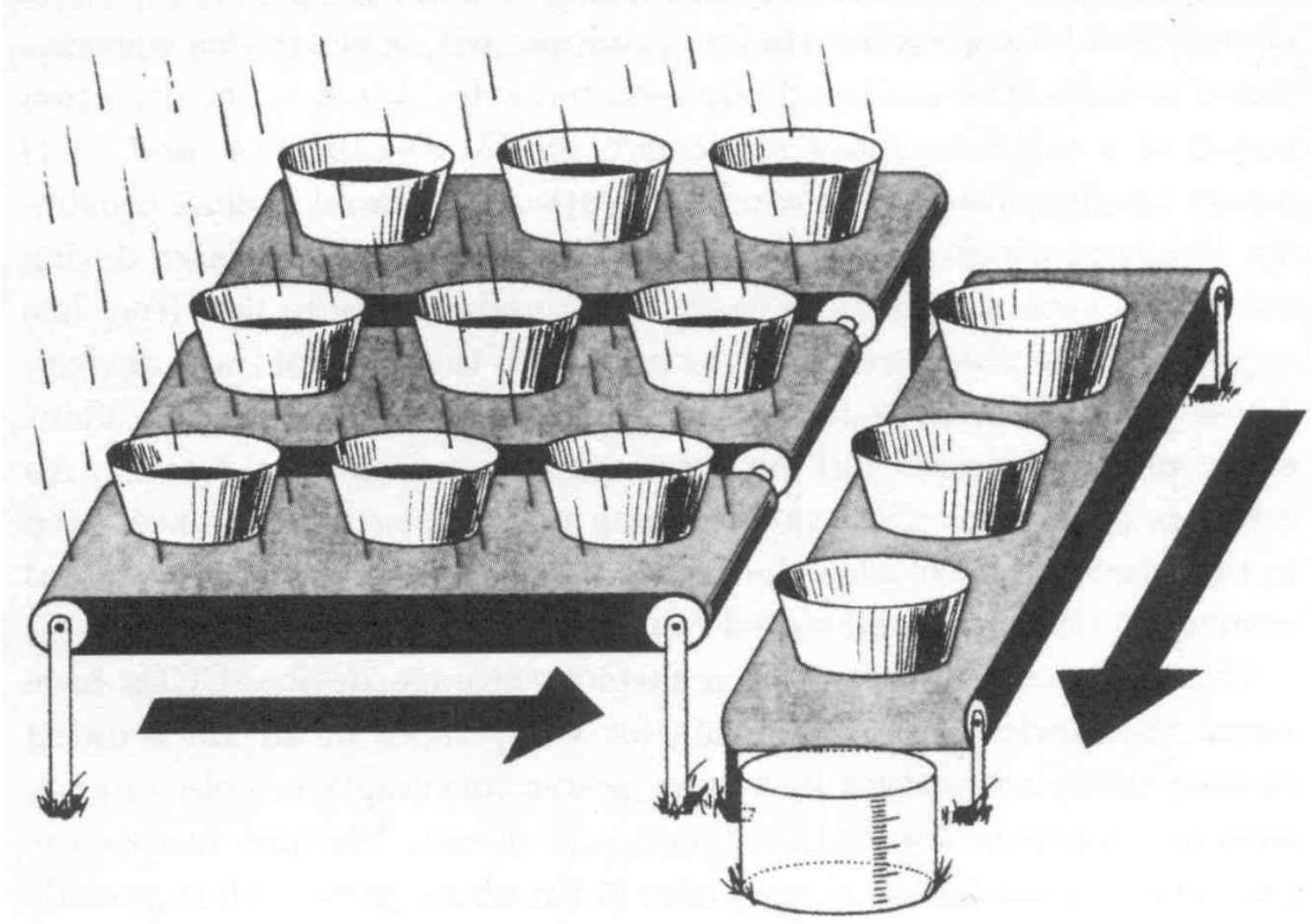
- Silicon absorbs light

from 300-1000 nm



CCD Light Bucket Pixel Array

- Individual CCD pixels (buckets) collect photons (raindrops)
- Electron transfer (conveyors) allows readout (collection)



CCD Image Types

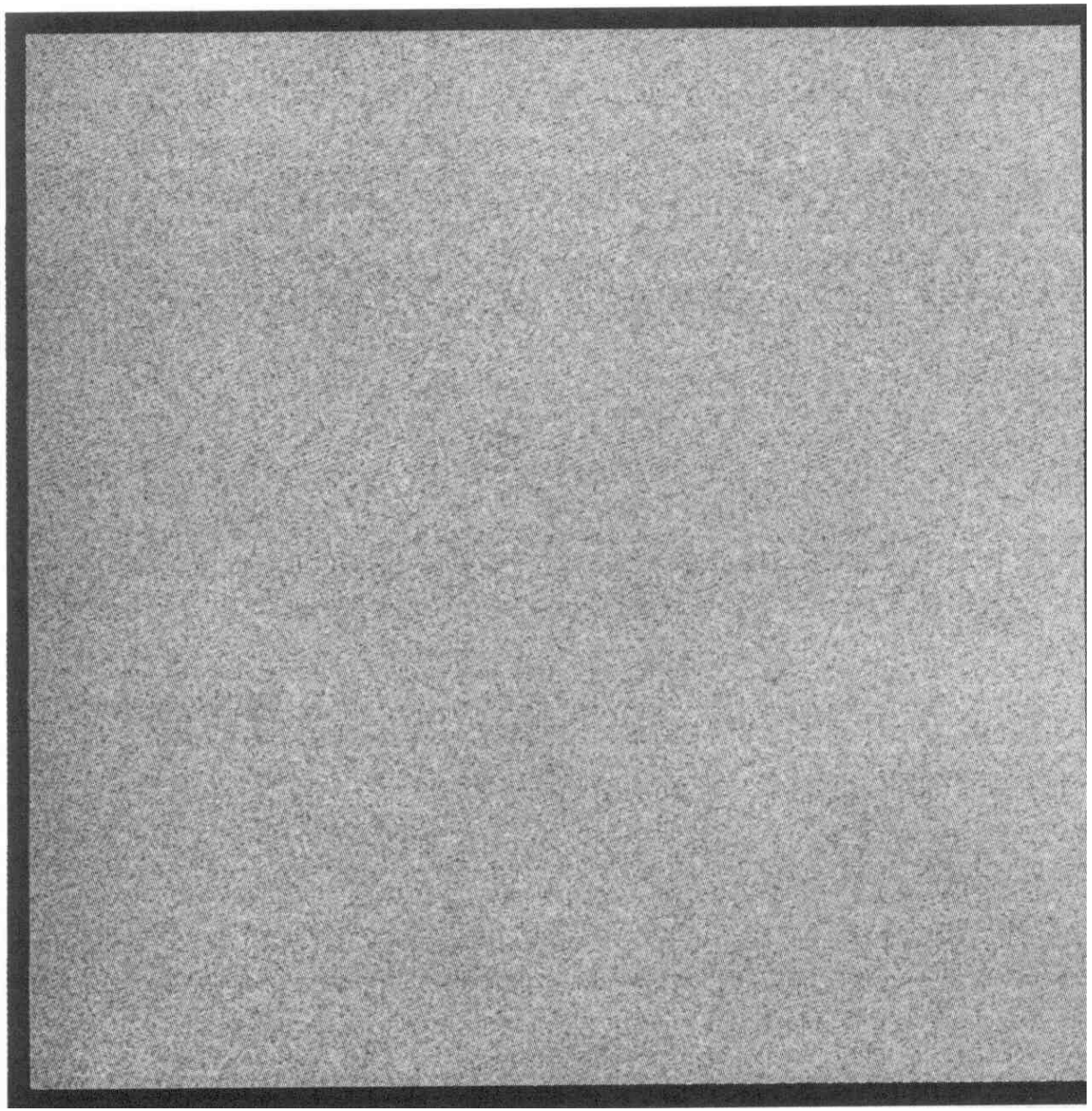
- Bias Image Frame
  - Determine underlying noise level caused by read out electronics
- Dark Image Frame
  - Determine contribution of thermal electrons from dark current
  - Dark current should increase linearly with time
  - Provide info on cosmic ray event rate, hot or bad pixels
  - Dark frame also includes bias level
- Flat Field Image Frame
  - Needed to correct for pixel to pixel variations in sensitivity
- Object Image Frame
  - Each pixel may contain signal, sky, dark current, noise, cosmic rays

Bias (Zero) Image Frame

What will the CCD electronic readout process yield without exposure to photons?

- Zero illumination (shutter closed)

- Zero exposure time, just readout the chip

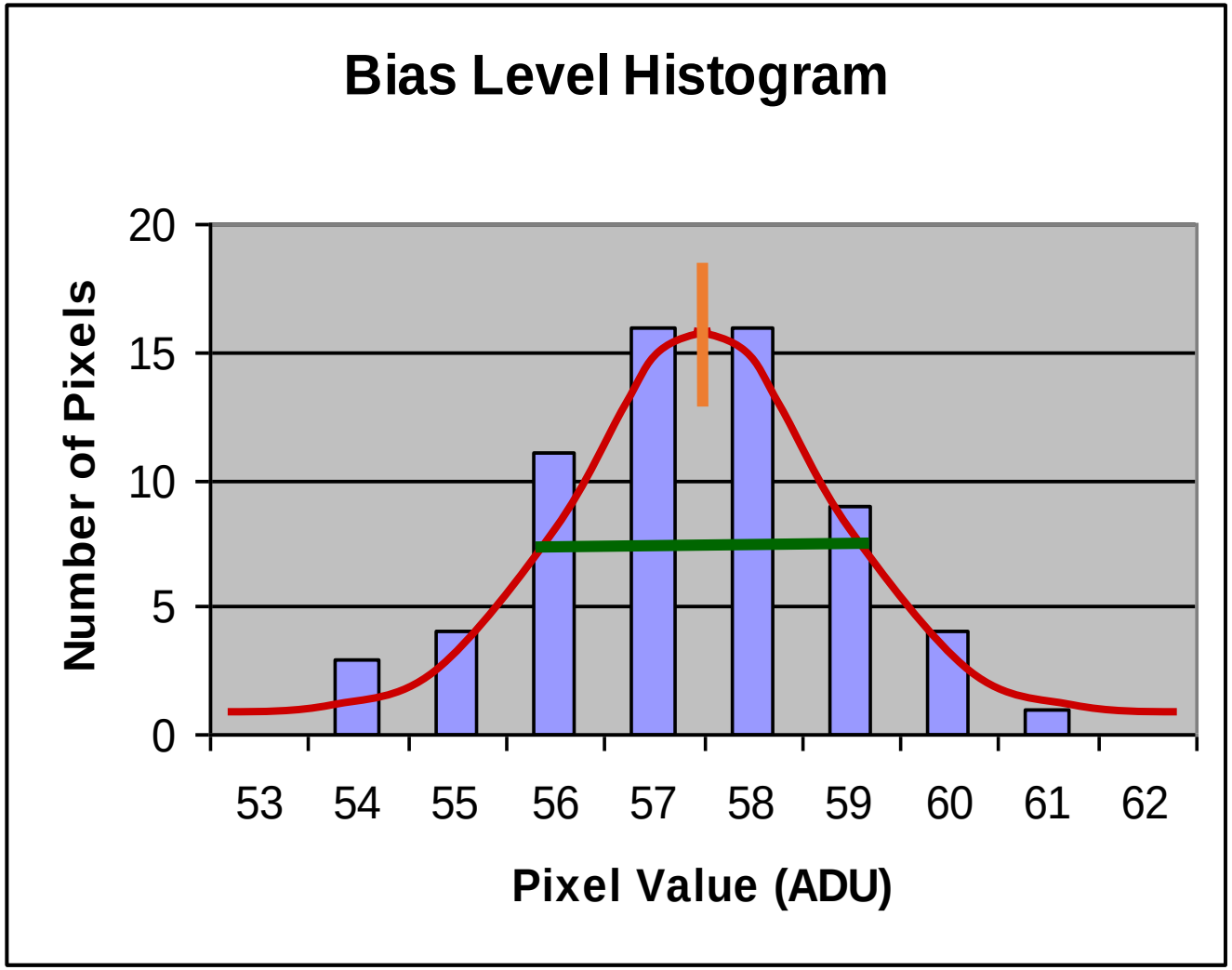


Level put in to avoid negative numbers in readout.

Bias Histogram: Bias Level and Read Noise

Mean = Estimator of the Bias Level

Standard Deviation = Estimator of the Read Noise

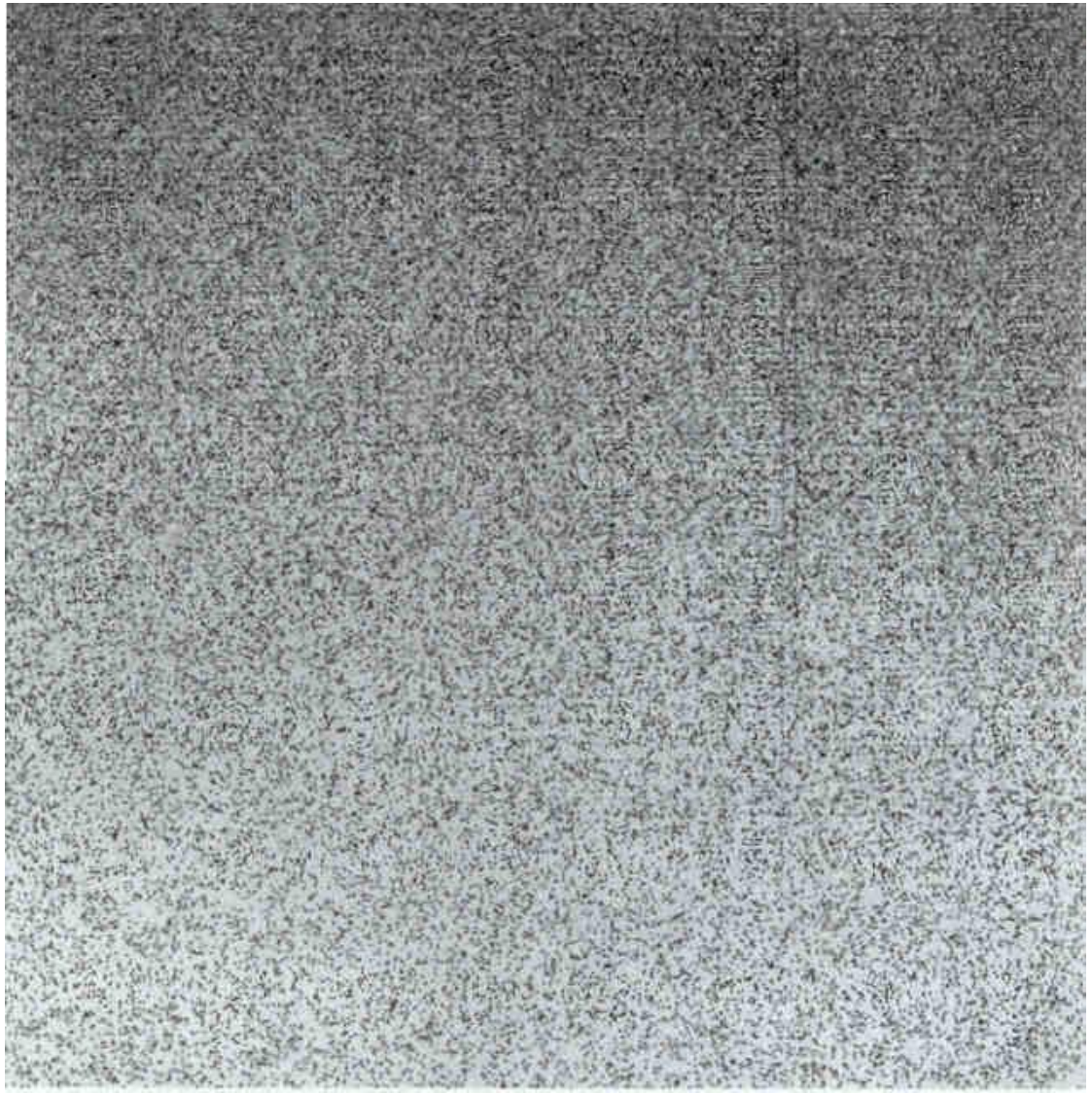


Dark Image Frame

What will the CCD electronics and readout process yield without exposure to photons, BUT with time integration?

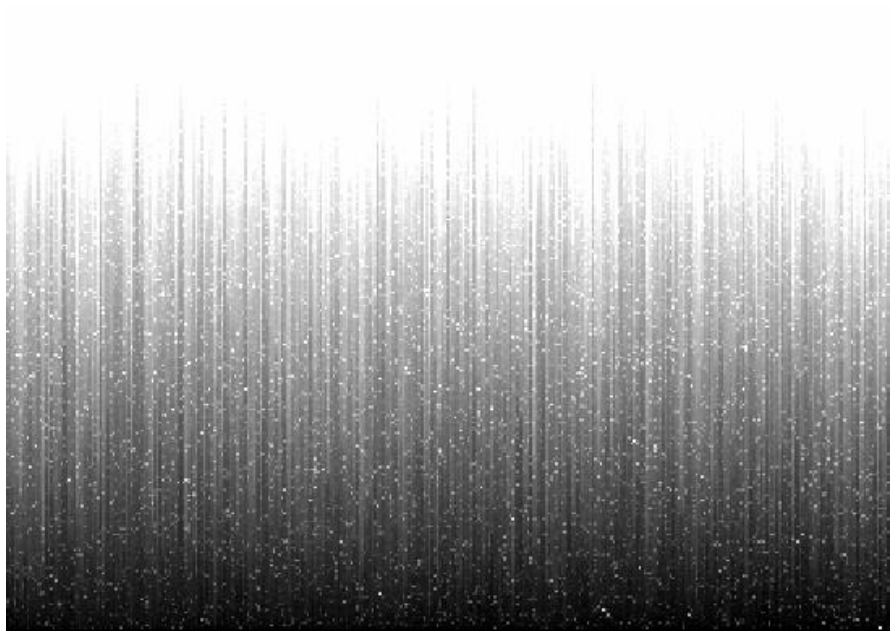
- Zero Illumination (shutter closed)

- Exposure times on par to that for object images.

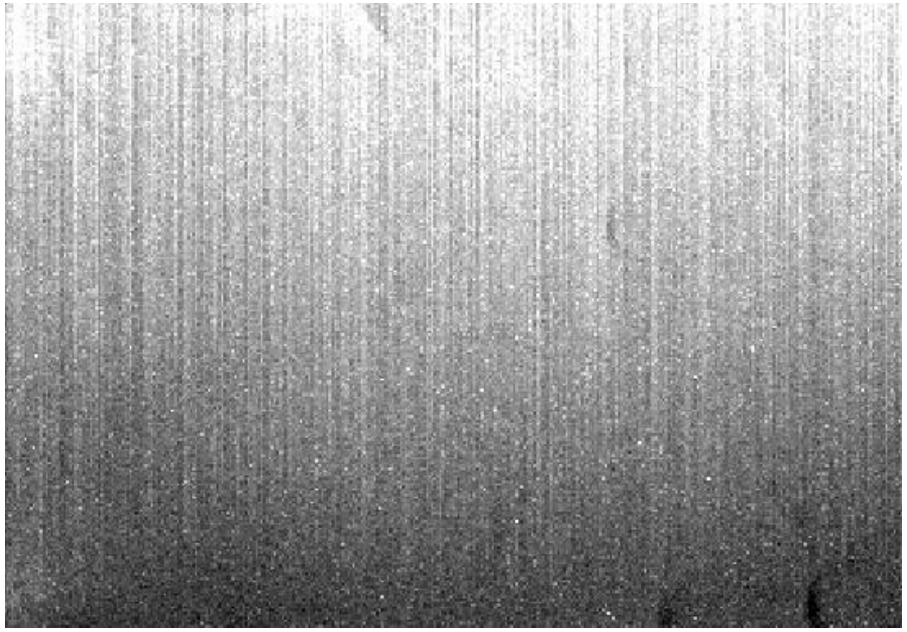


Dark Current and Cooling

dark image +10°C, 1.0 seconds



dark image -10°C, 1.0 seconds

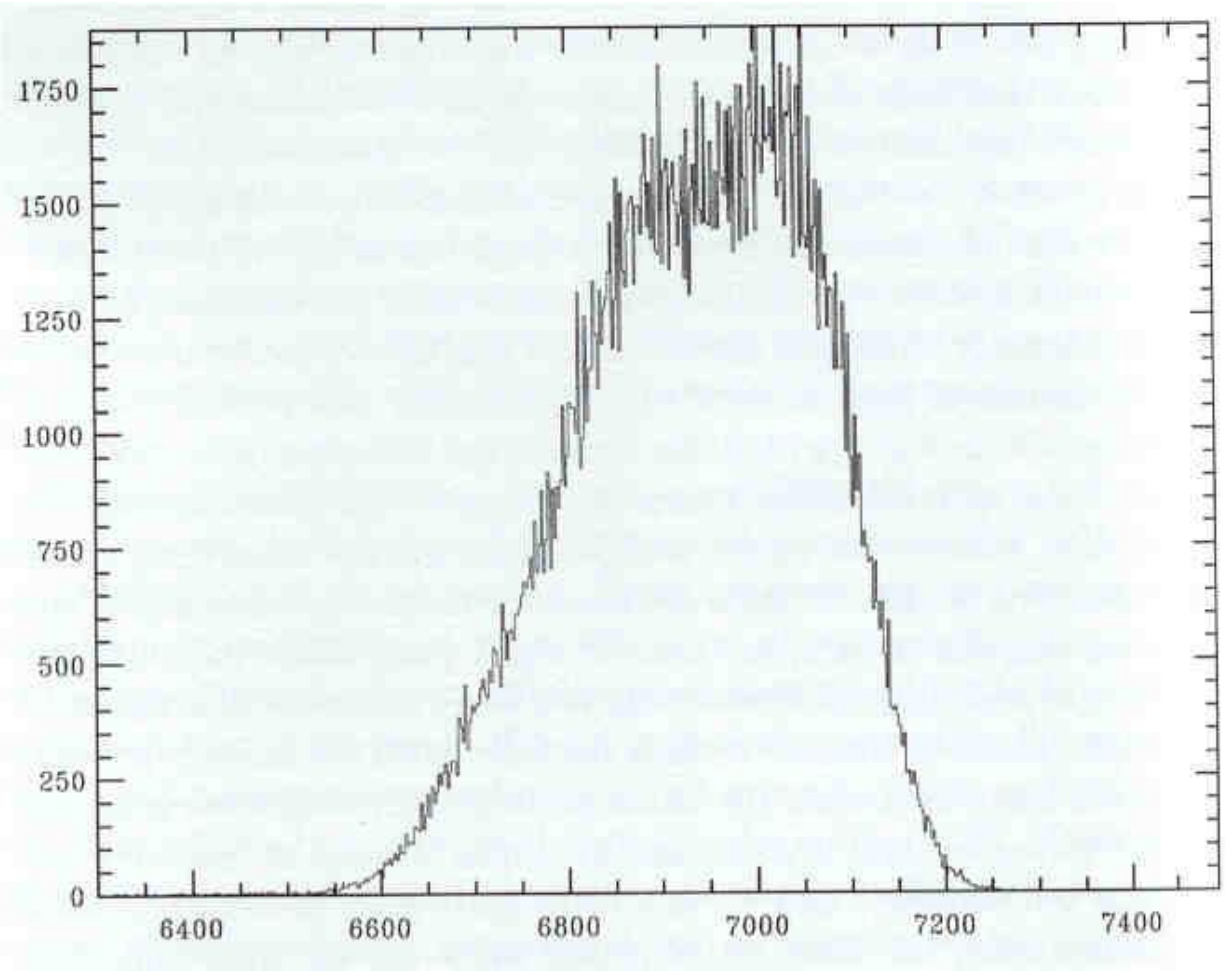


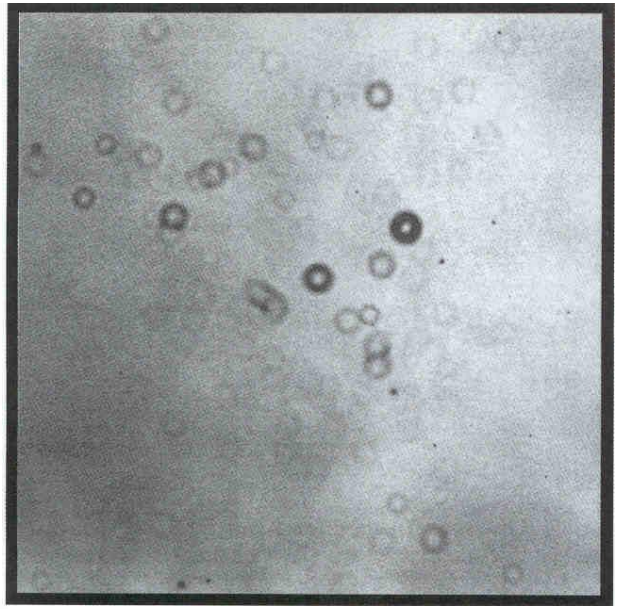
There is much more signal from thermal electrons in the “warmer” image at left

Notice the signal increases toward the bottom of the image because of heat generated in the amplifier and A/D converter as the readout digitization progresses. Sometimes this will be skewed to the readout corner.

Flat Field Image Histogram

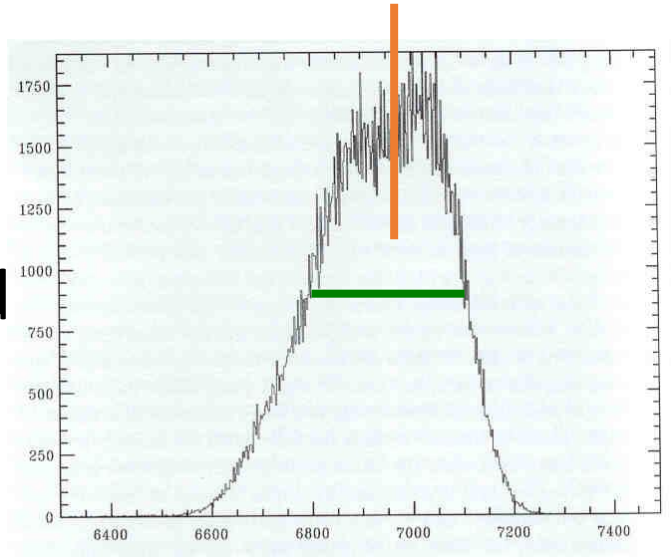
The flat field histogram is nearly gaussian with a slight skew toward smaller values from dust donuts, shadows and imperfections on or near the chip.





Flat Field Histogram Statistics

The mean pixel value of the flat field histogram is used to create a normalized flat field needed to correct all data images.



Normalized Flat = Raw Flat Field ÷ Mean Pixel Value

Flat Fielding Objective

What is a GOOD flat field?

- A good flat field allows measurements to be transformed from instrumental values into a standard system that agrees with other observers.

- The Test: Include a single flat field image and treat it as an object image. Take a normalized mean flat field image and apply it to one of your single flat field images.

- The proof of a good flat field (and data reduction process) is to test if the variations in the resulting flat image are $\leq 1\%$.

- Variations > 2% indicate a problem somewhere!

Flat Fielding Methods

How to get a GOOD flat field?

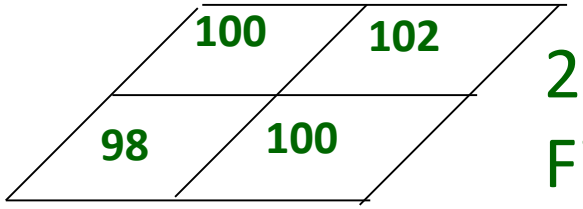
- Twilight sky exposure (no stars)
- White screen illuminating the inside of the dome
- White plastic diffuser attached to telescope entrance pupil
- Median night sky exposures

Flat	Flatness	S/N	Color
Twilight Sky	Variable	Variable	Too Blue
Dome	Marginal	High	Too Red
Median Night Sky	Good	Low	Good Match

- A good compromise is to combine Dome (S/N) flats with median night sky (color balance) flats.

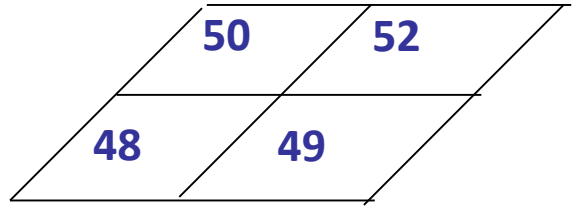
Flat Field Application Exercise

- Correcting images with flats



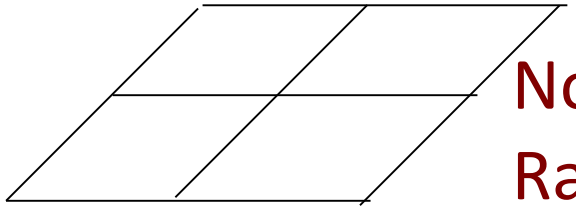
2x2 Raw Flat Field Pixels

2x2 Raw Object Image



Mean Flat Field Pixel Counts = 100

(100 + 100 + 102 + 98) ÷ 4

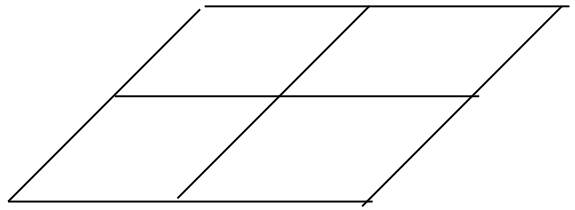


Normalized Flat =

Raw Flat Field Counts ÷ Mean

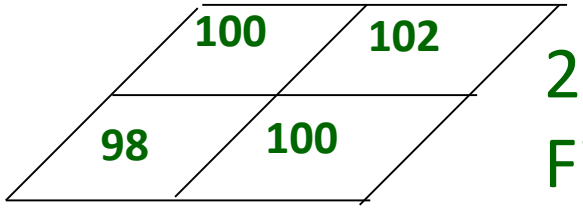
Corrected Object Pixel Counts =

Pixels of Interest ÷ Normalized Flat



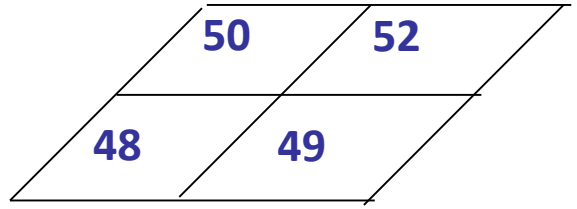
Flat Field Application Exercise

- Correcting images with flats



2x2 Raw Flat Field Pixels

2x2 Raw Object Image



Mean Flat Field Pixel Counts = 100

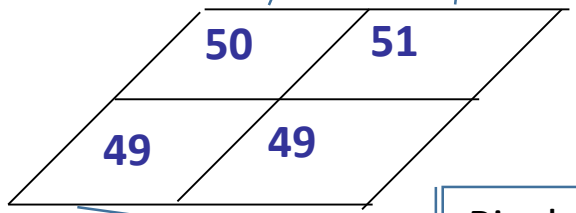
(100 + 100 + 102 + 98) ÷ 4

Normalized Flat =

Raw Flat Field Counts ÷ Mean

Corrected Object Pixel Counts =

Pixels of Interest ÷ Normalized Flat

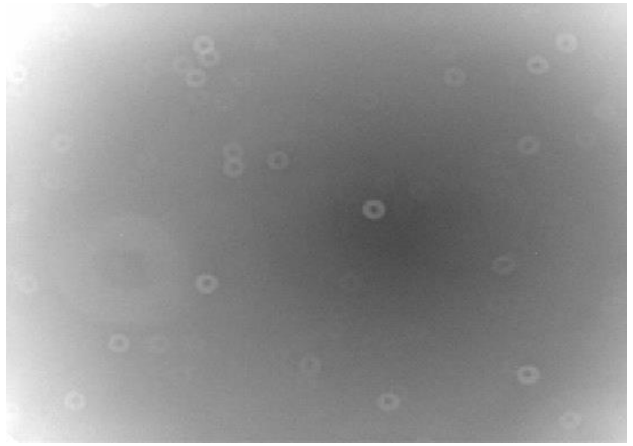


Pixel left alone (avg)

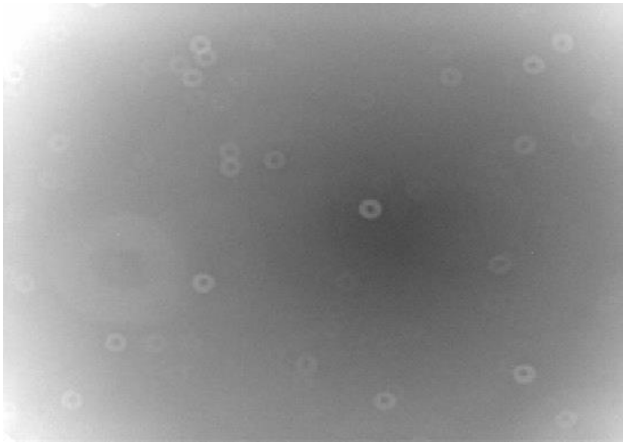
Pixel suppressed, Above average sensitivity

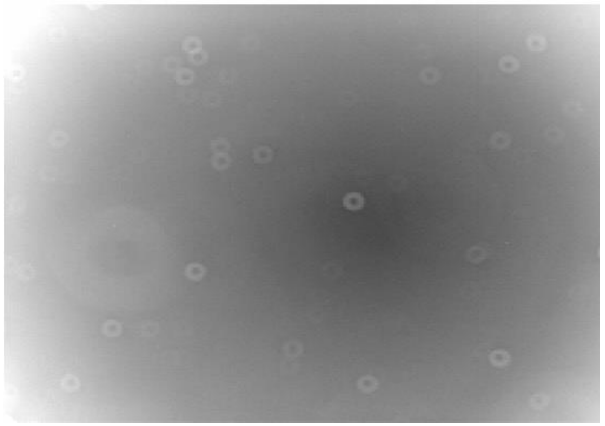
Pixel enhanced, Below average sensitivity

Flat Field Test

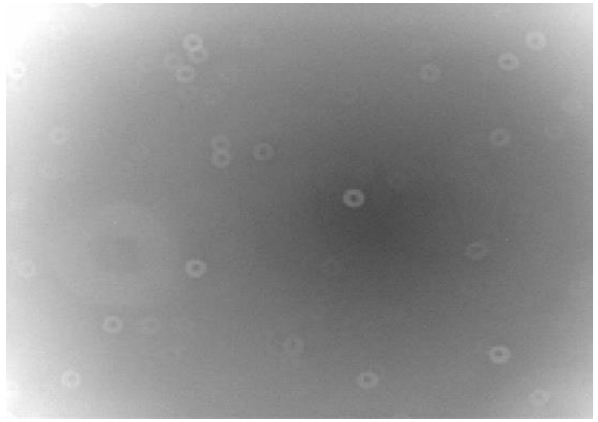


Average Flat ÷ Average Pixel Value (41,837.) = Normalized Flat

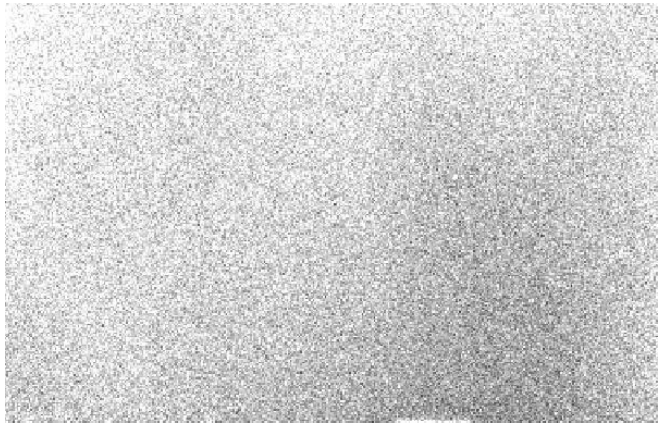




Single Flat (Image) ÷



Normalized Flat =



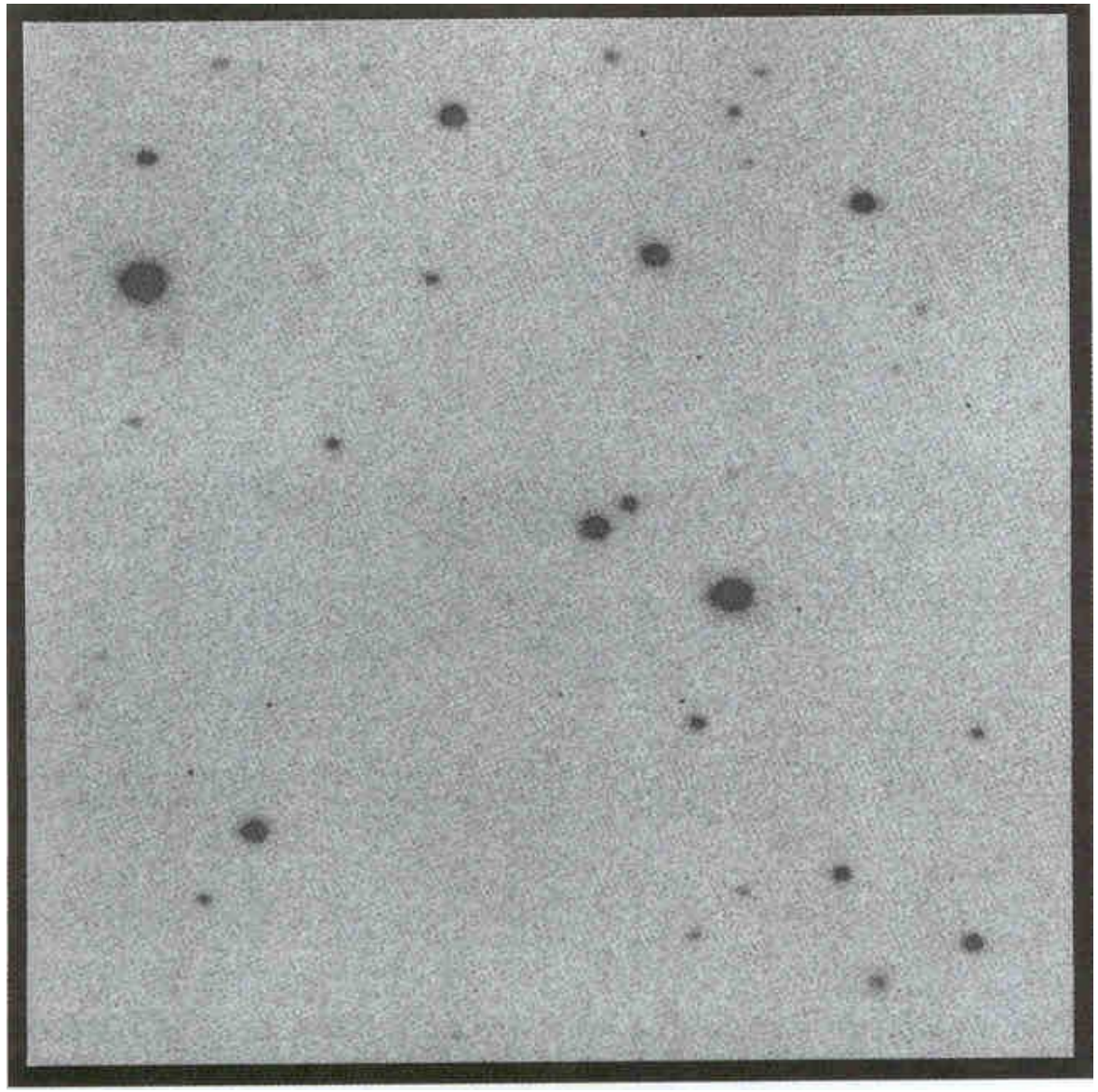
Corrected Image (variations < 1%)

Object Image

Finally, a DATA Frame!

- Contains all source targets of interest plus background.

- Exposure time depends upon science objectives.



Standard Raw Image Calibrations for SCIENCE

- Create average calibration images from multiple frames (10)
  bias, dark, flat
- Subtract Average Bias image (Zero) from dark, flat, objects
  [Average Dark - Zero] = Net Dark
  [Average Flat - Zero] = Net Flat
  [Object - Zero] = Net Object
- Subtract Net Dark image from Net Flat and Net Objects
- Determine the mean pixel value of the [Net Flat - Net Dark]

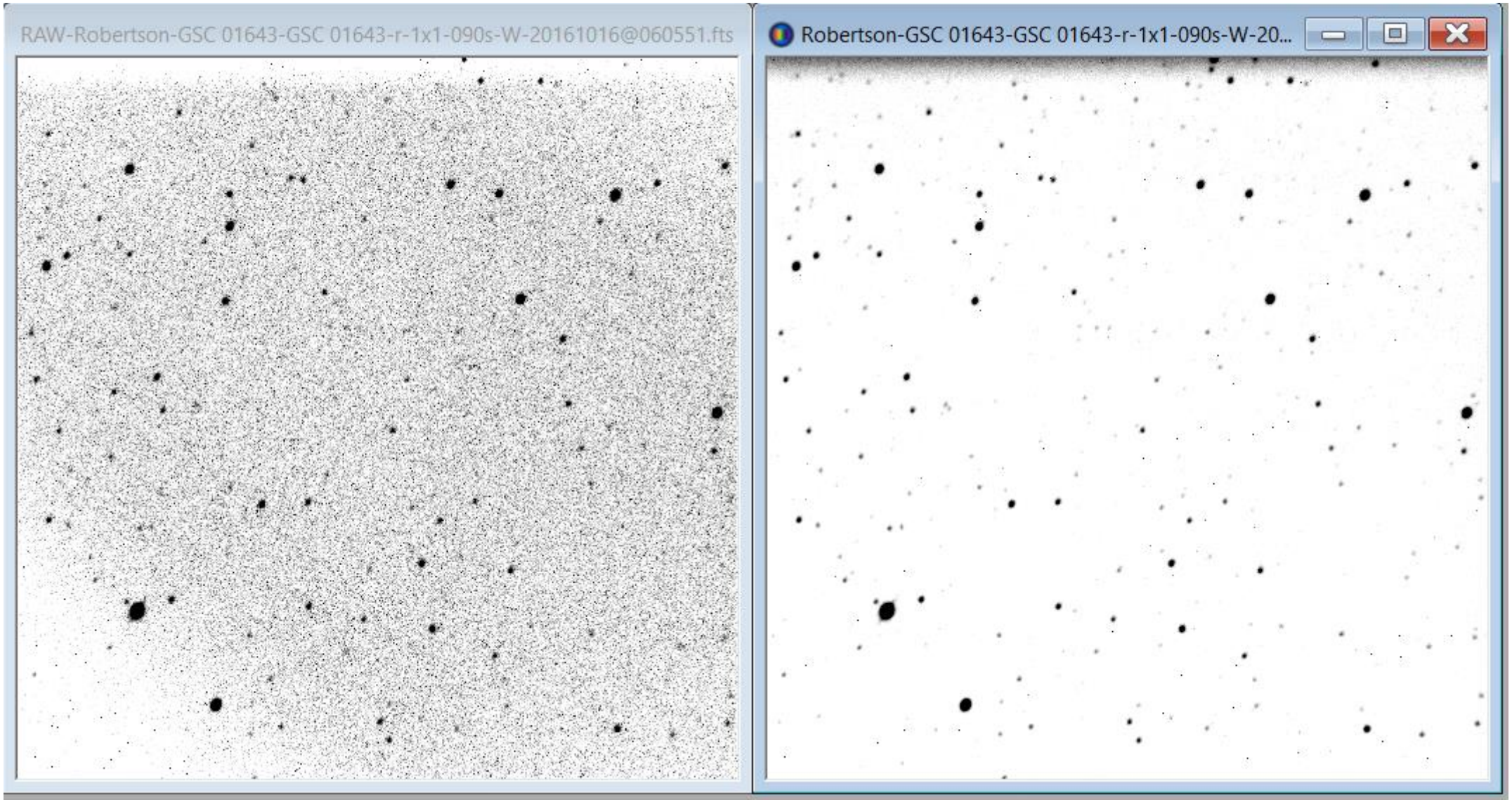
- Apply Flat Field correction

Normalized Flat = [Net Flat - Net Dark] ÷ [Mean Pixel Value]

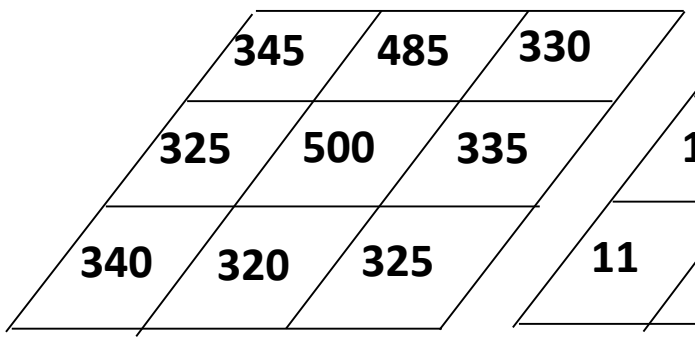
Final Object = [Net Object - Net Dark] ÷ [Normalized Flat]

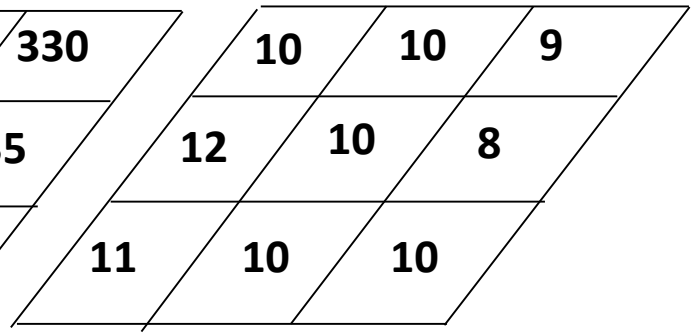
RAW

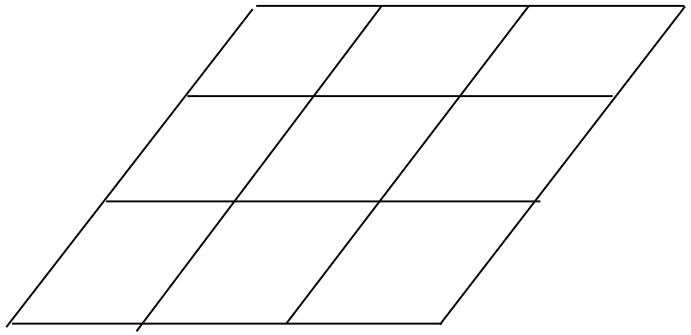
CALIBRATED

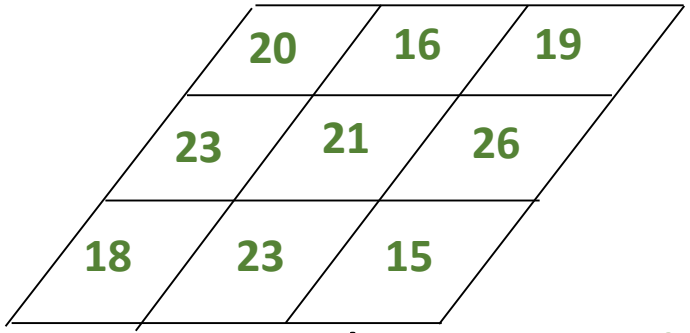


Apply Calibrations to Object Image



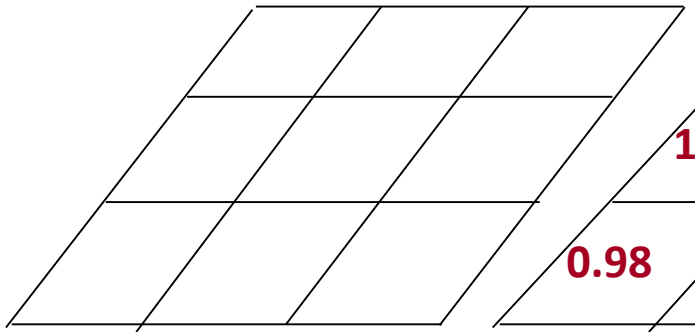


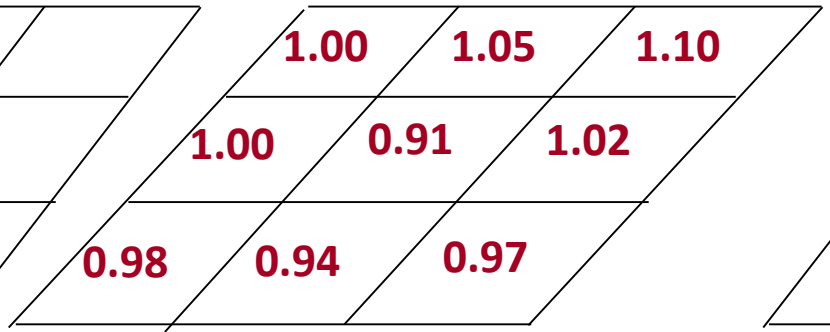


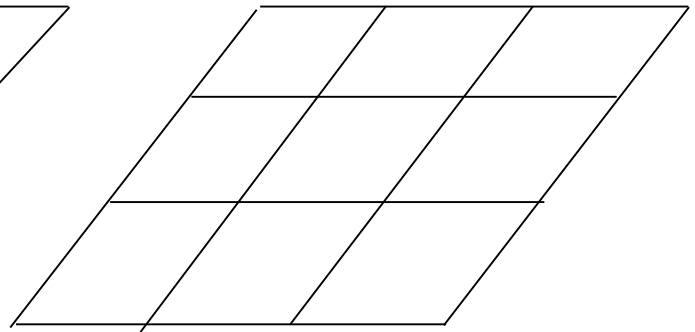


(Object Image - Average Bias) - Net Dark = Net Object

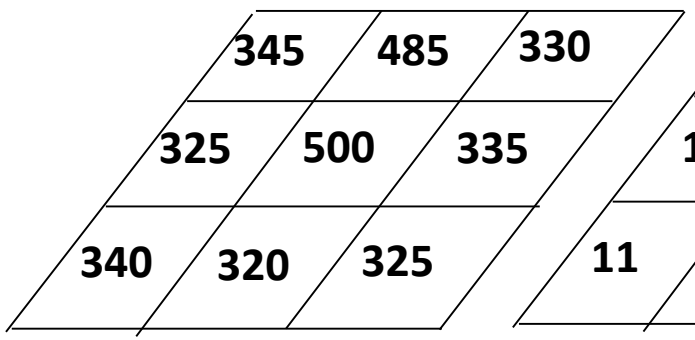
Net Object ÷ Normalized Flat = Corrected Object

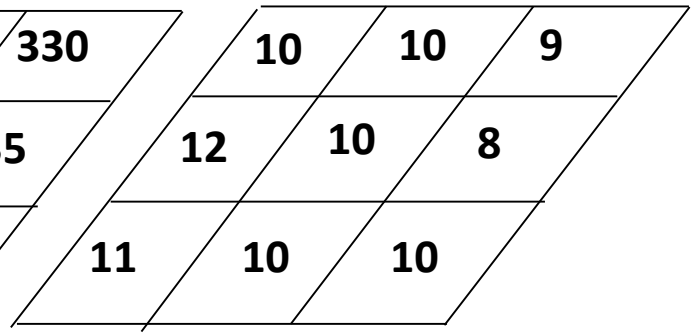


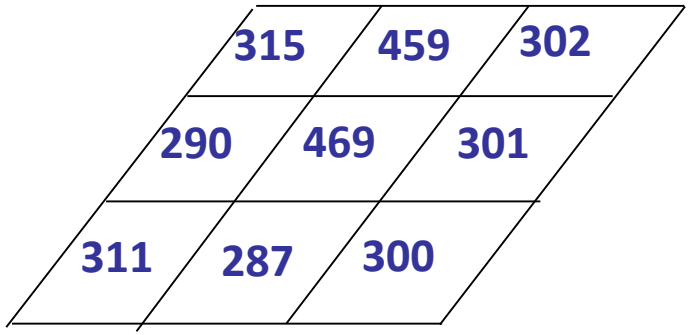


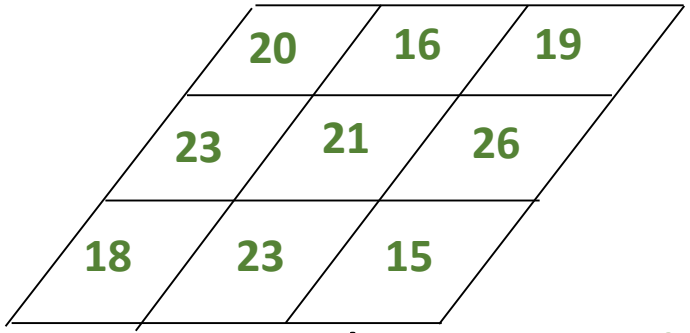


Apply Calibrations to Object Image



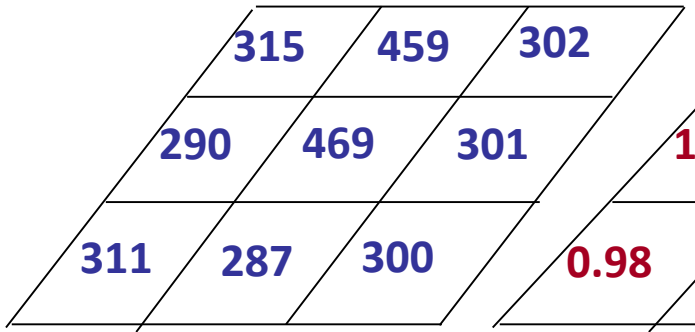


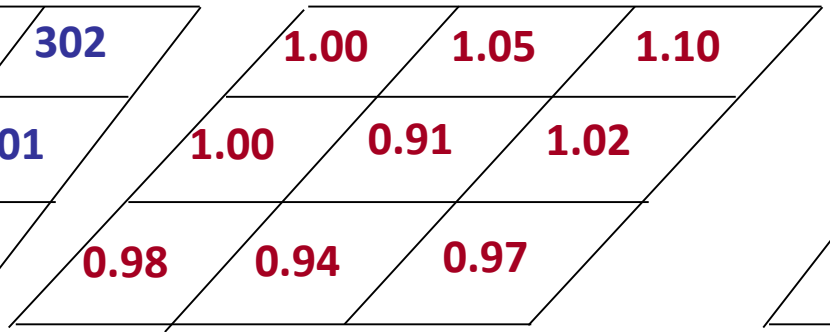




(Object Image - Average Bias) - Net Dark = Net Object

Net Object ÷ Normalized Flat = Corrected Object





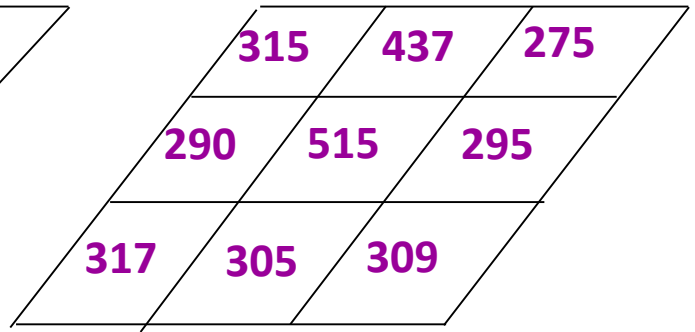
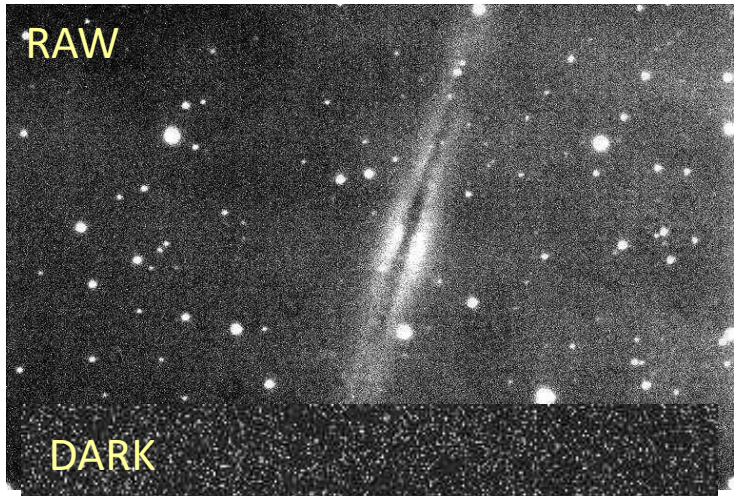
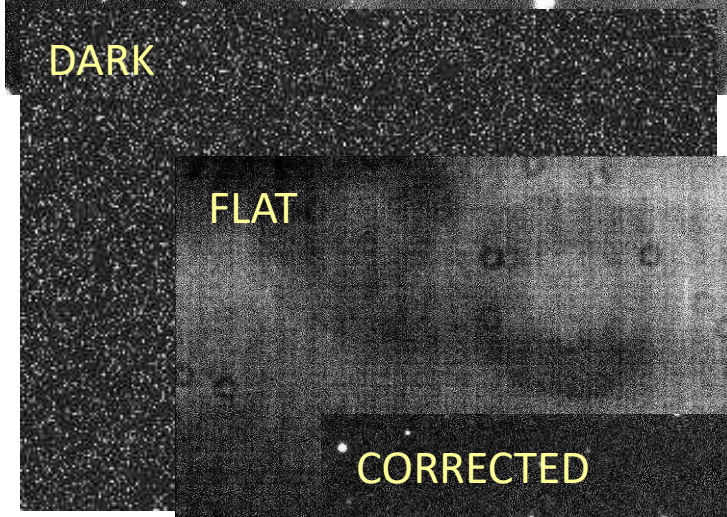
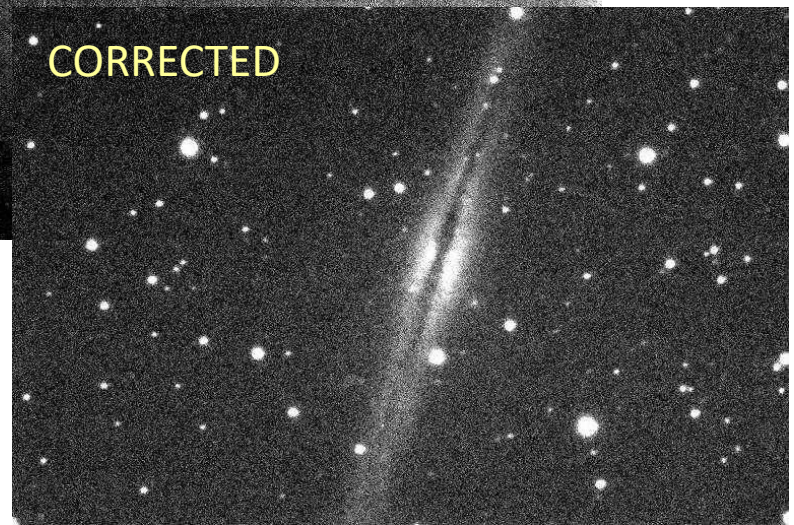
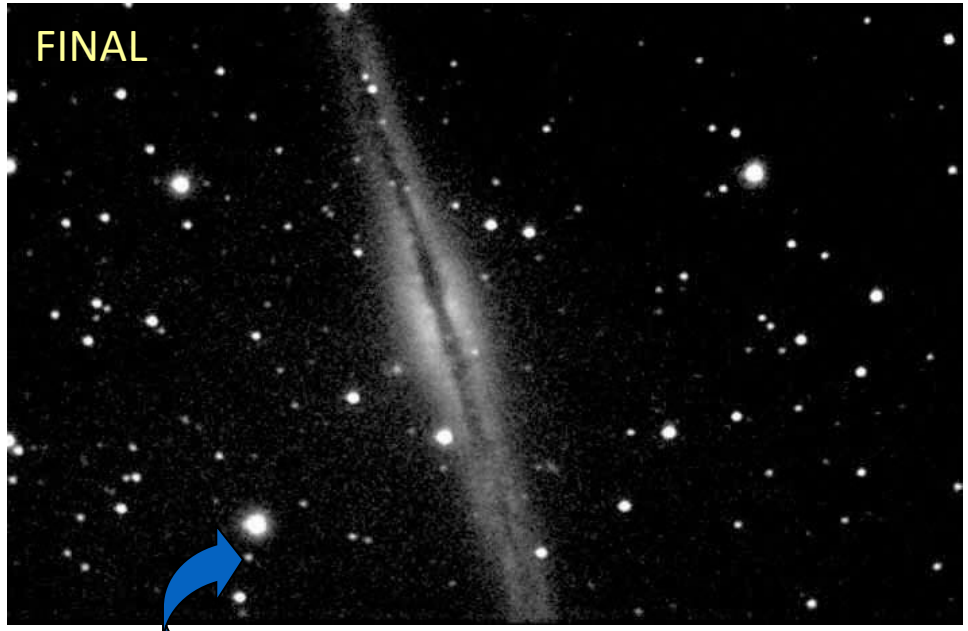


Image Calibration Correction





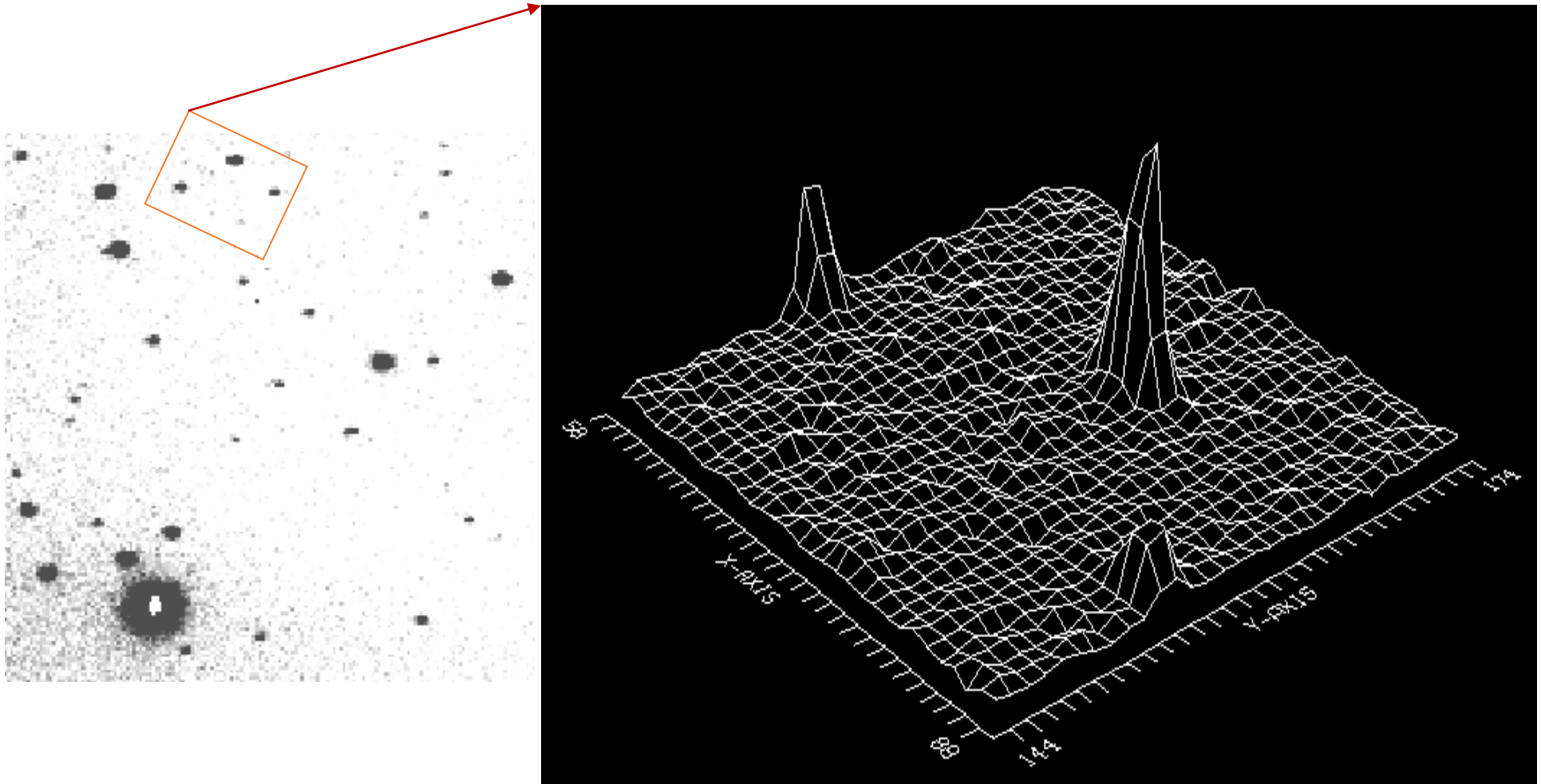




Dark Subtracted,
Flat Fielded (calibrated),
then Mirror Flipped,
Multiple Co-Added
(for aesthetics).

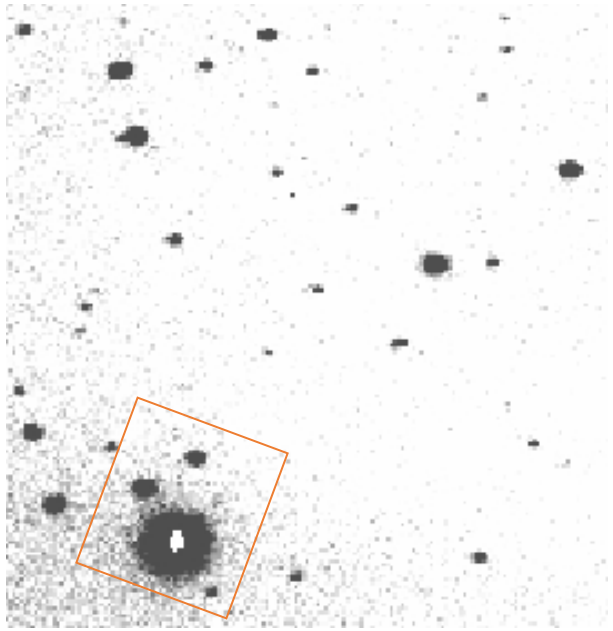
Stellar Profiles

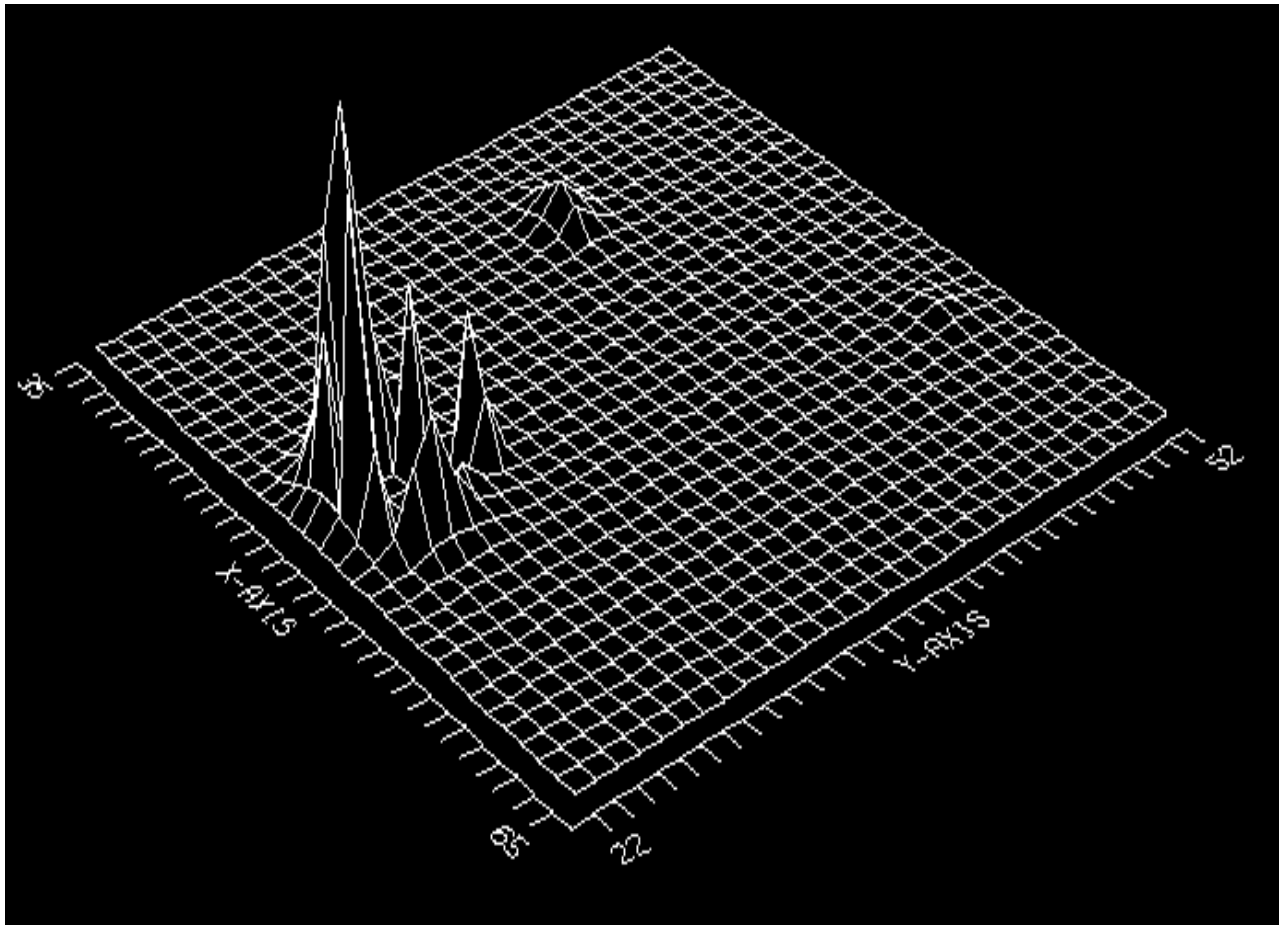
- The intensity distribution of stars can be characterized by the point spread function (PSF).



Saturated Stellar Profile

Saturation can sometimes cause the mistaken use of the "sign" bit of the CCD chip. This causes values greater than the A/D converter can handle to be interpreted as "negative."



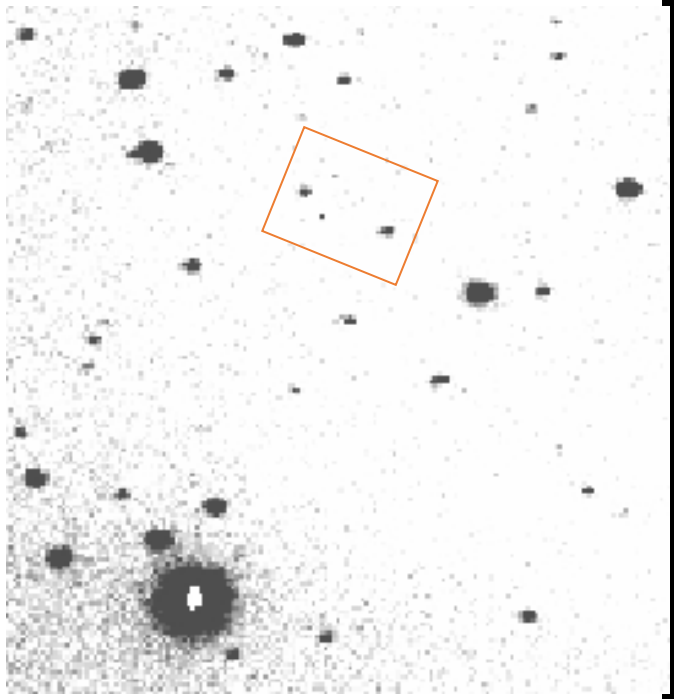


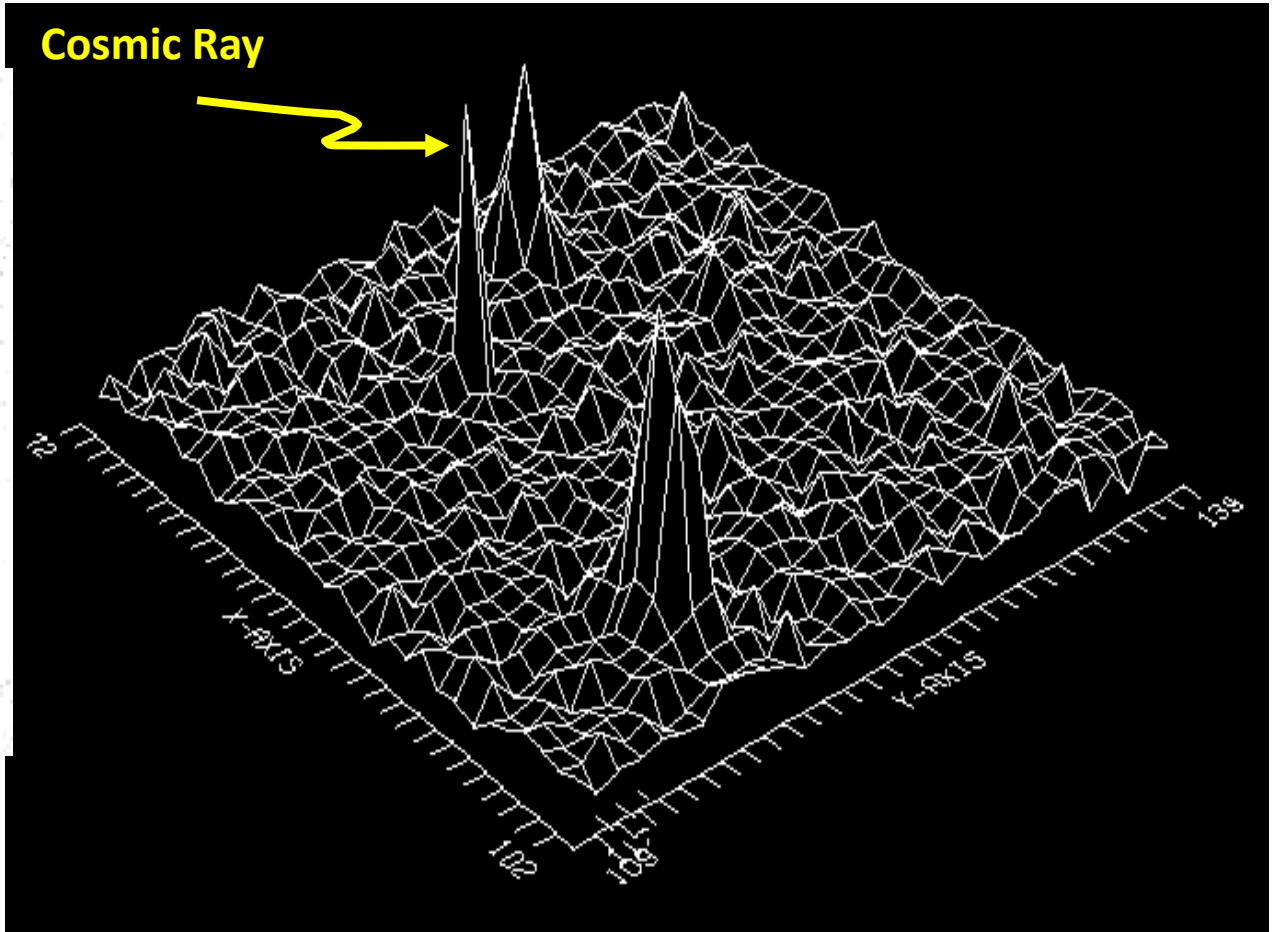
Cosmic Ray versus Stellar Profile

The FWHM of stars is much larger than that of cosmic rays.

Cosmic rays are usually sharp spikes covering ~ 1 pixel,

not a point spread function shape.





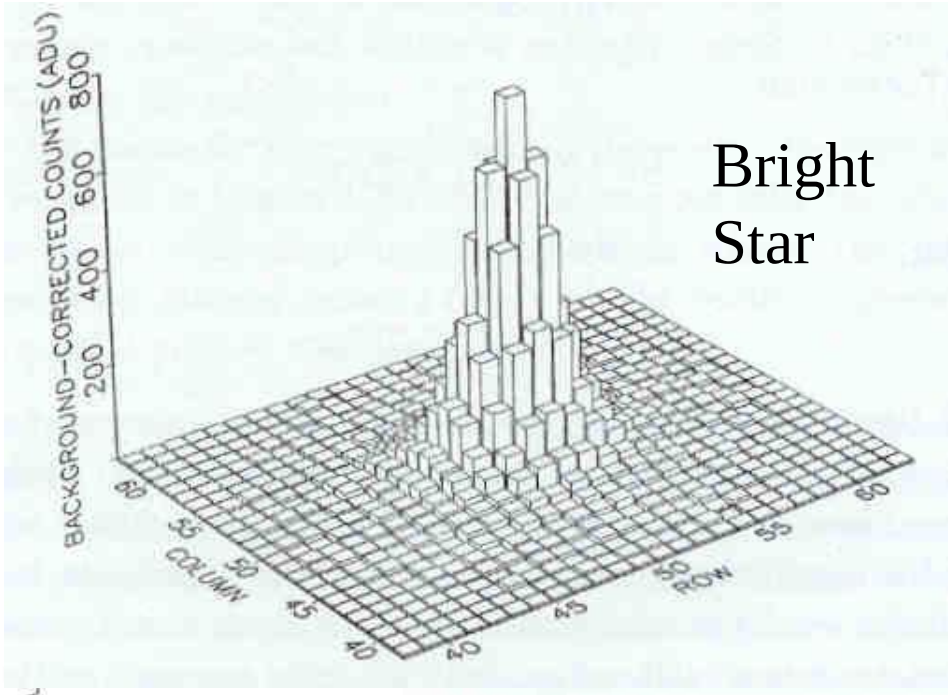
Stellar Profiles

CCD Stellar Profile (PSF)

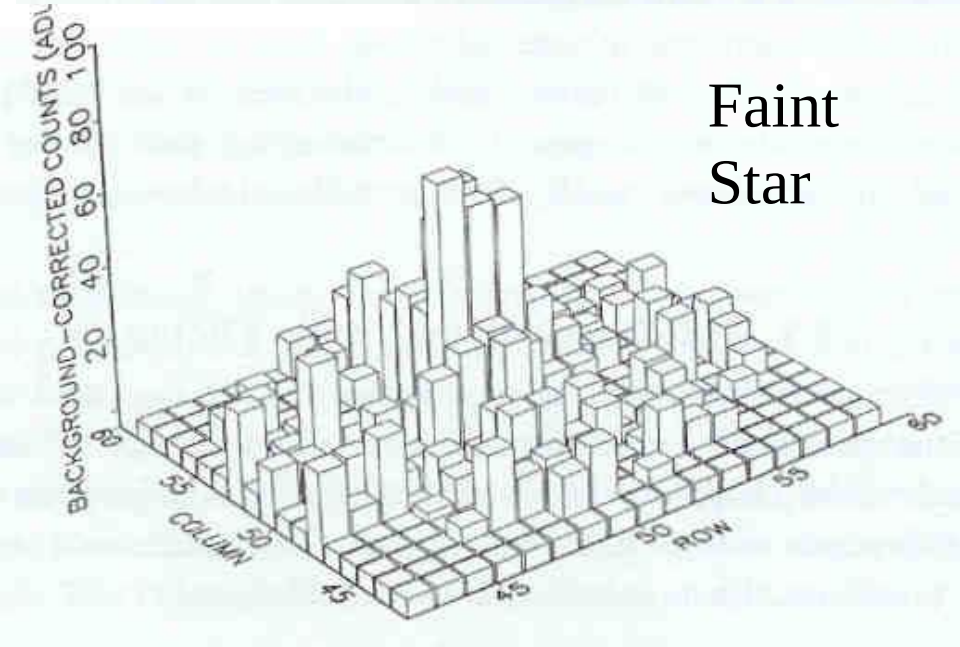
(a.k.a. Point Spread Function)

This profile is identical for all stars because of the optical system and seeing conditions.

Only the peak changes with stellar intensity.



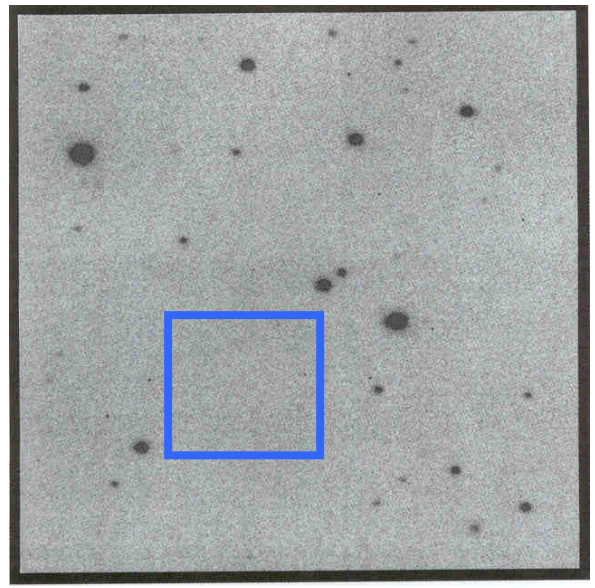
Bright Star



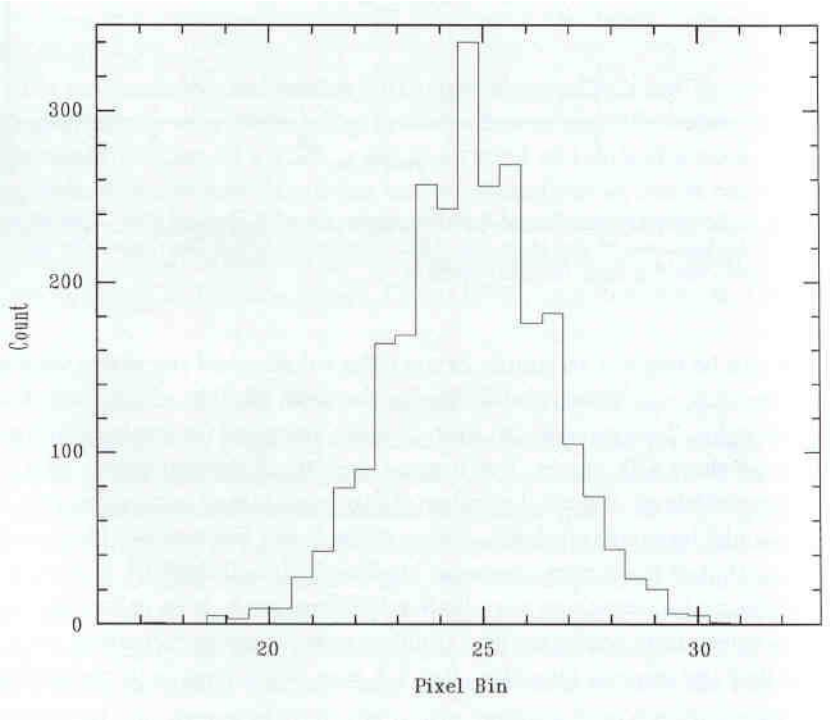
Faint Star

Sky Background Histogram

Estimation of the background (sky)* can be done by selecting a region of interest.



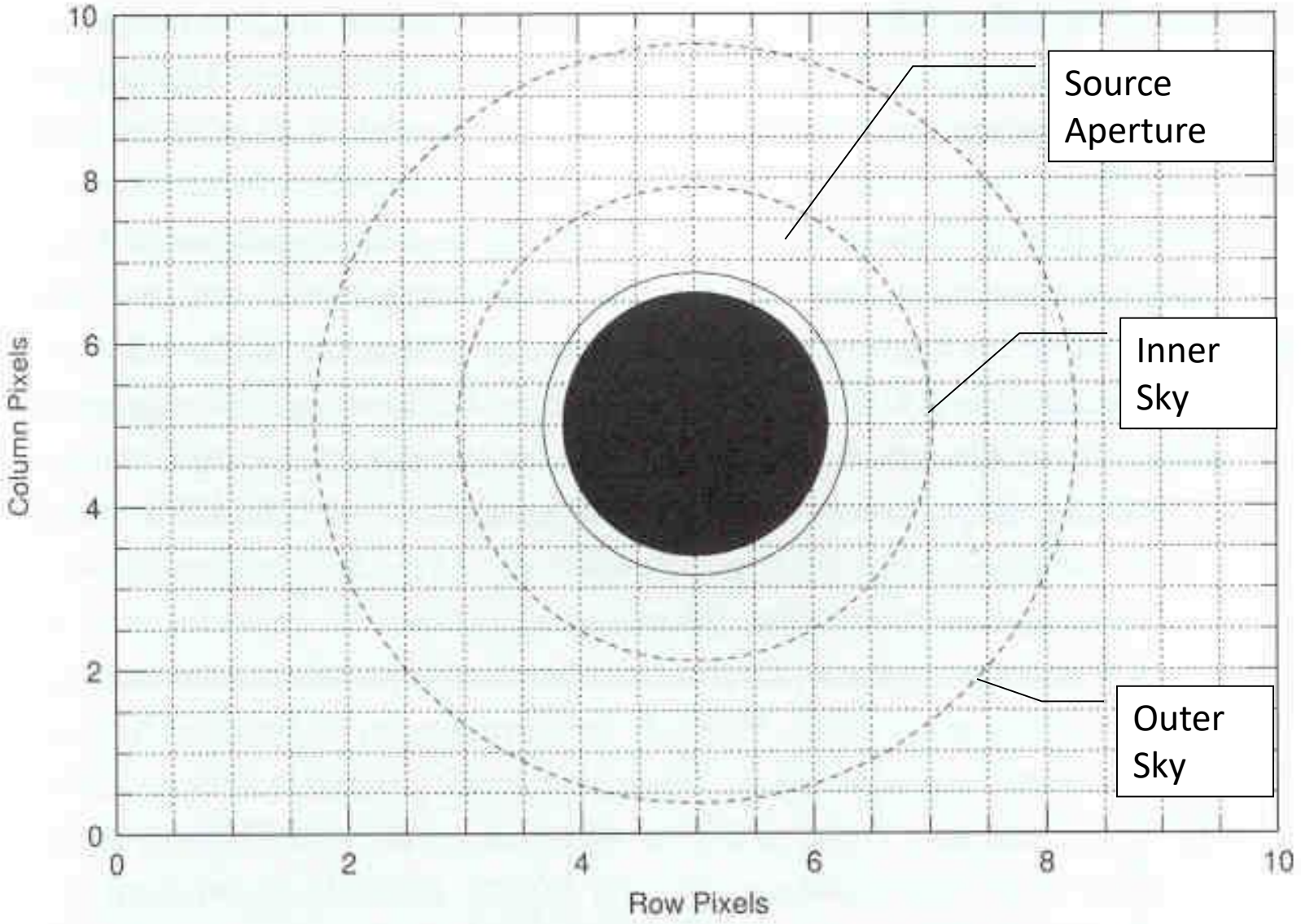
*The number of pixels used to determine the sky background should be ≥ 3× the number of pixels used in any aperture to determine the signal of the source.



The median or mode of the sky pixels is taken as the background.

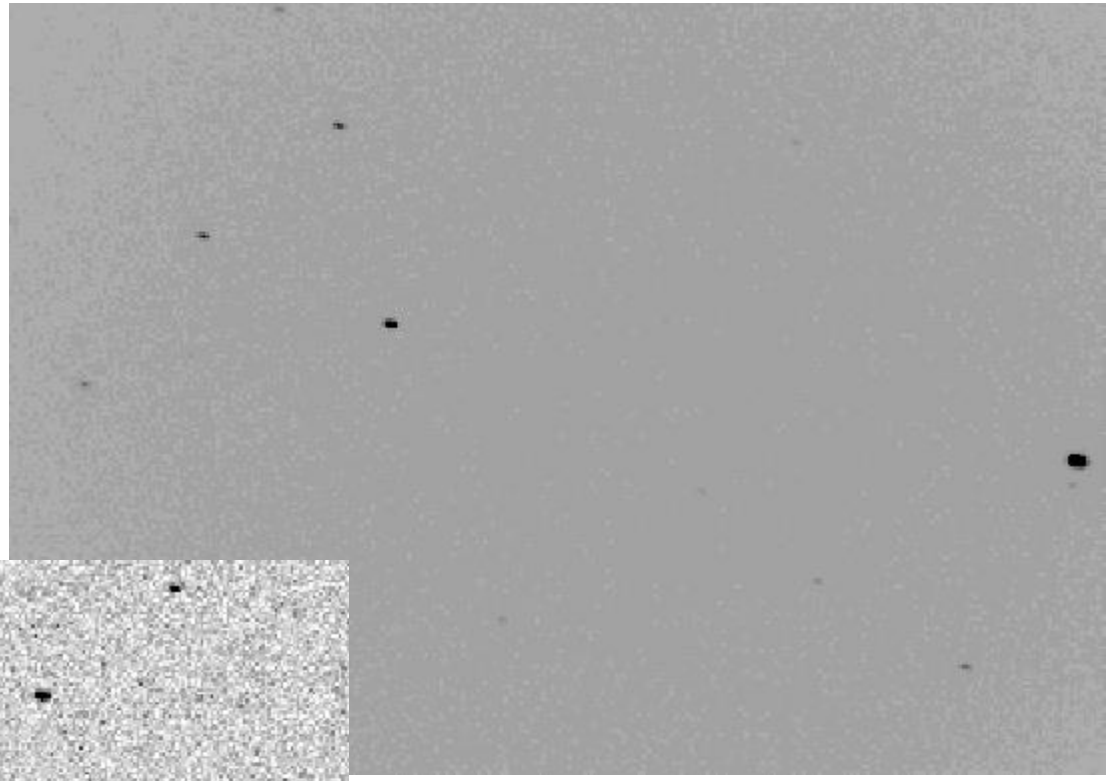
Stellar Annuli when performing photometry

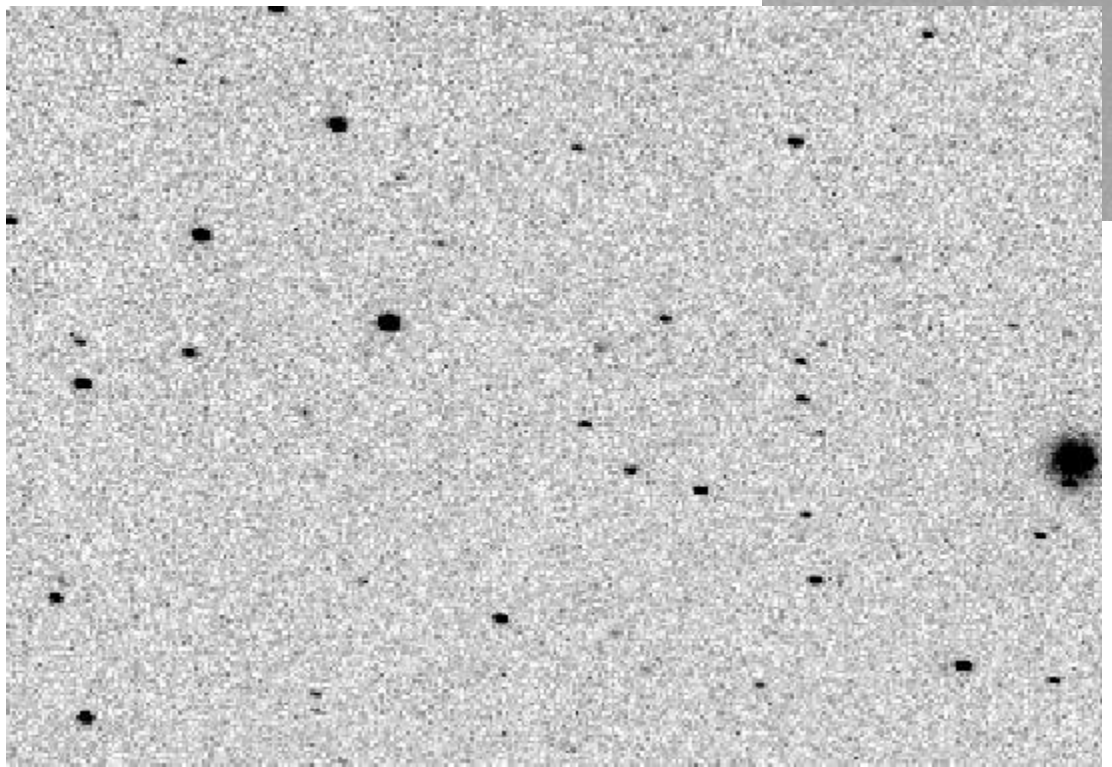
- Idealized star with aperture annuli selected for star and sky.



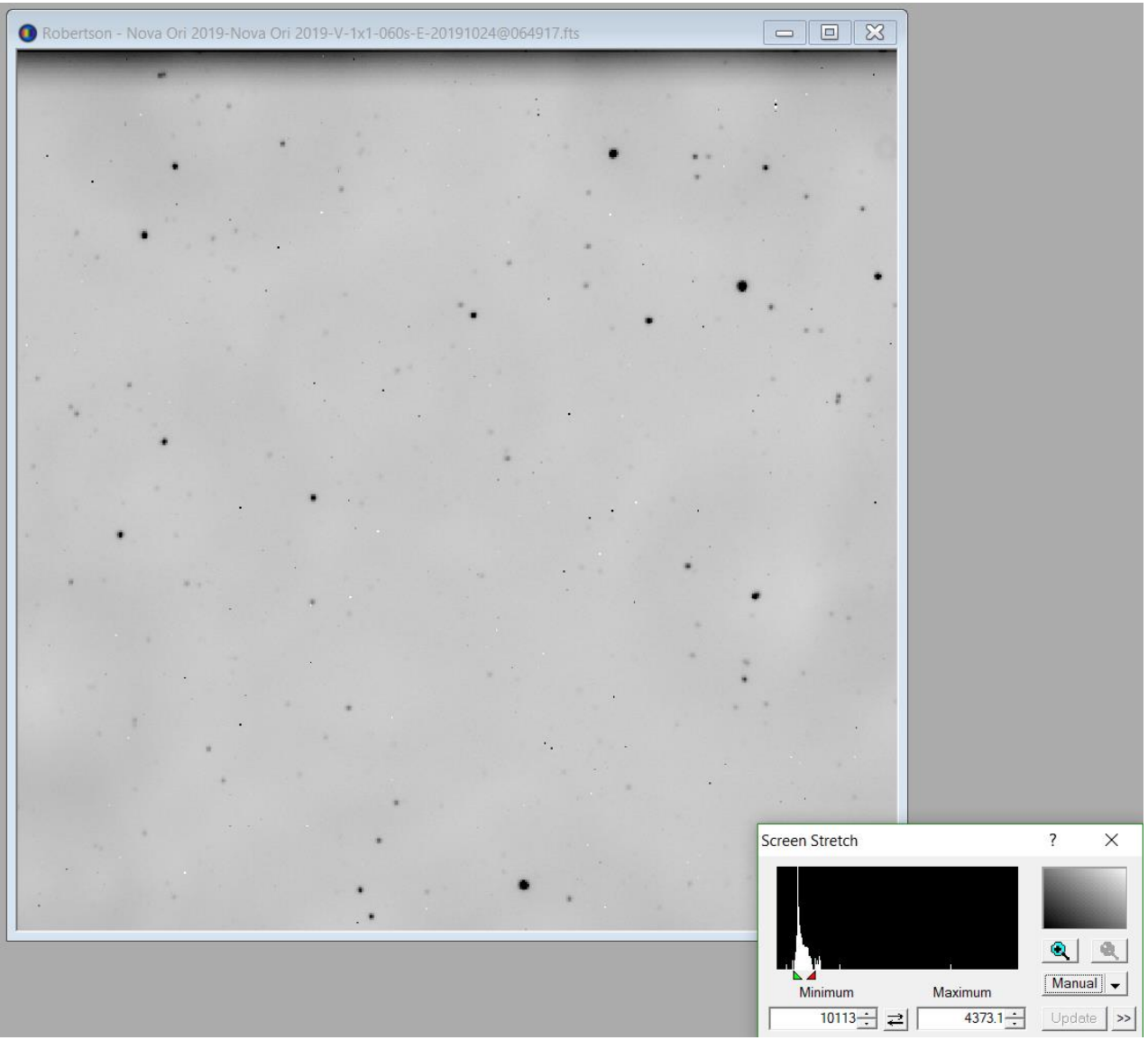
Identical Images

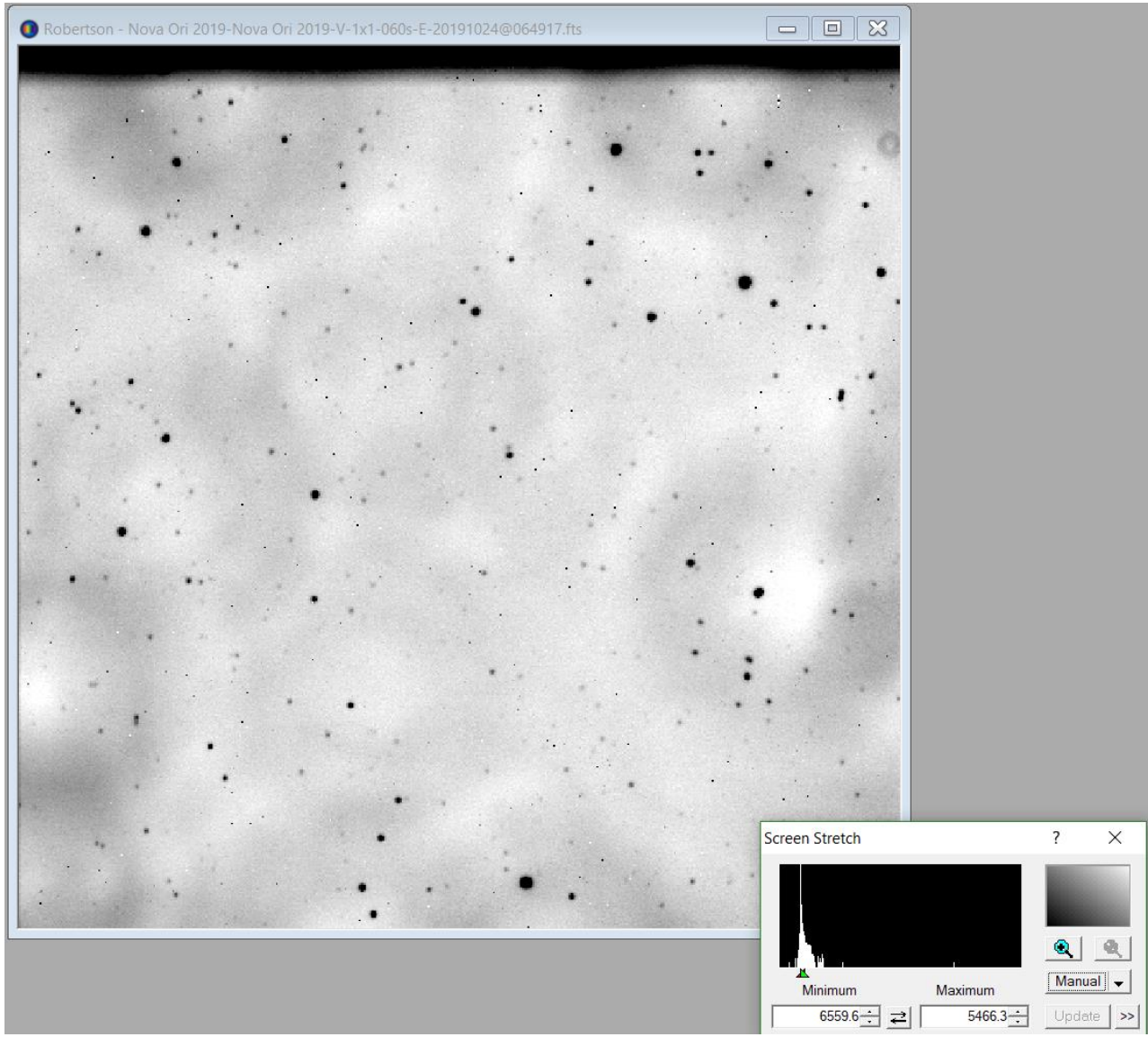
Image displayed with 256 grayscales covering entire dynamic range (0-65535 counts).



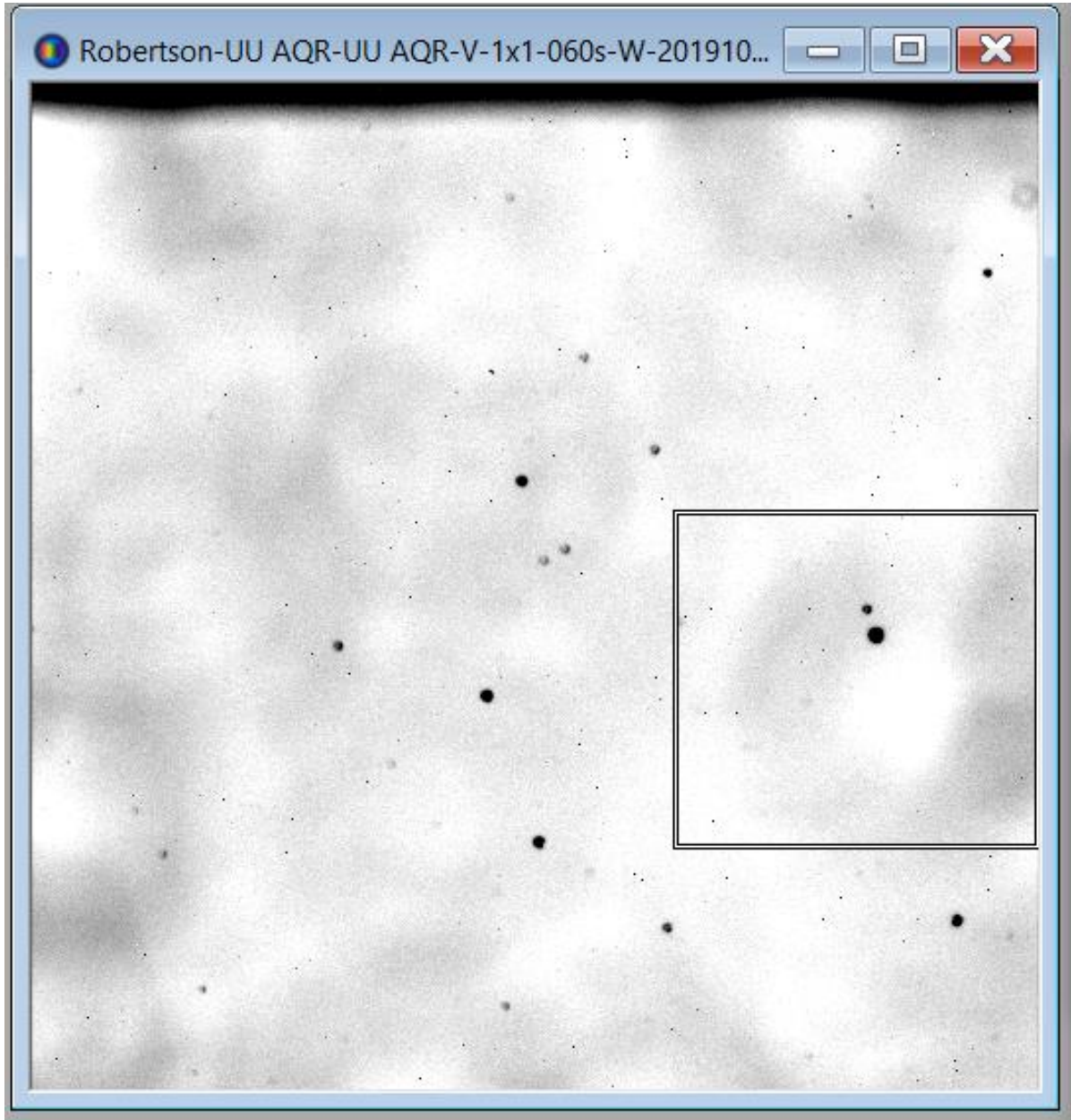


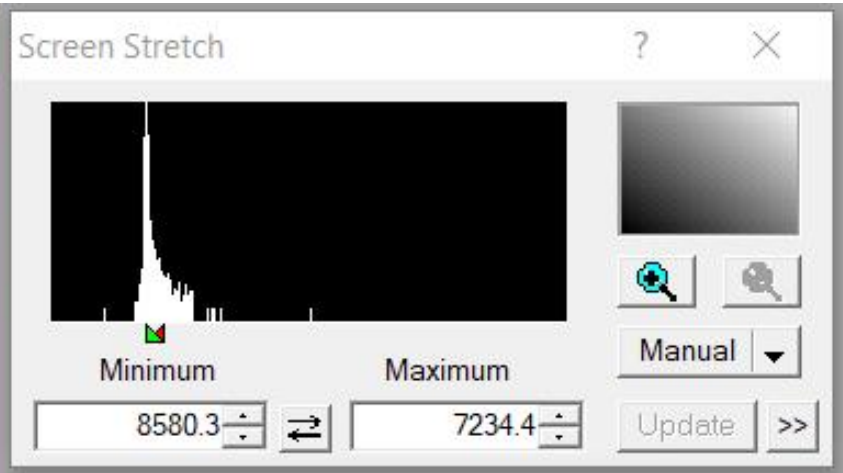
Same image displayed with 256 grayscales assigned to values around the histogram mean (250-500 counts).

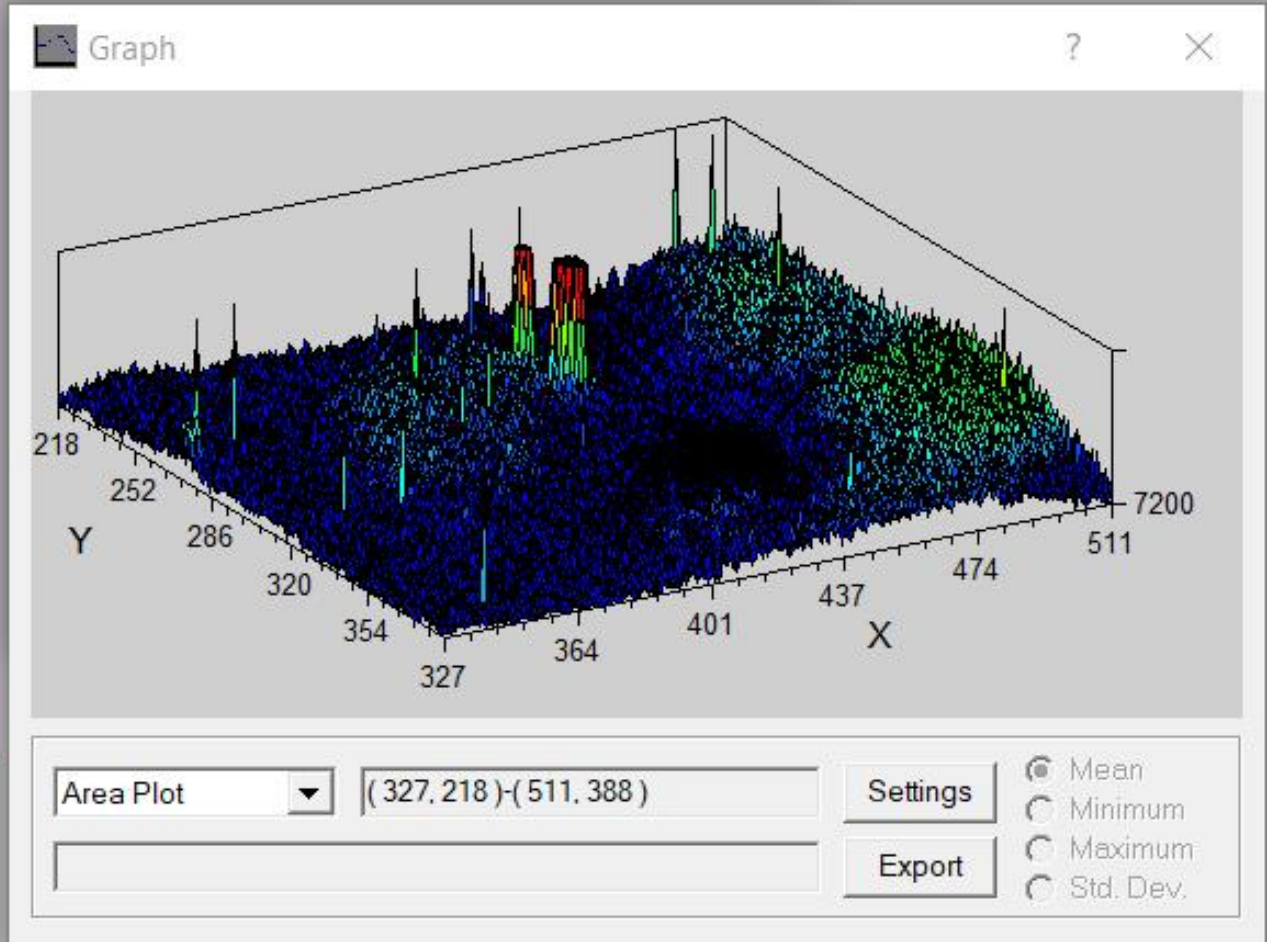




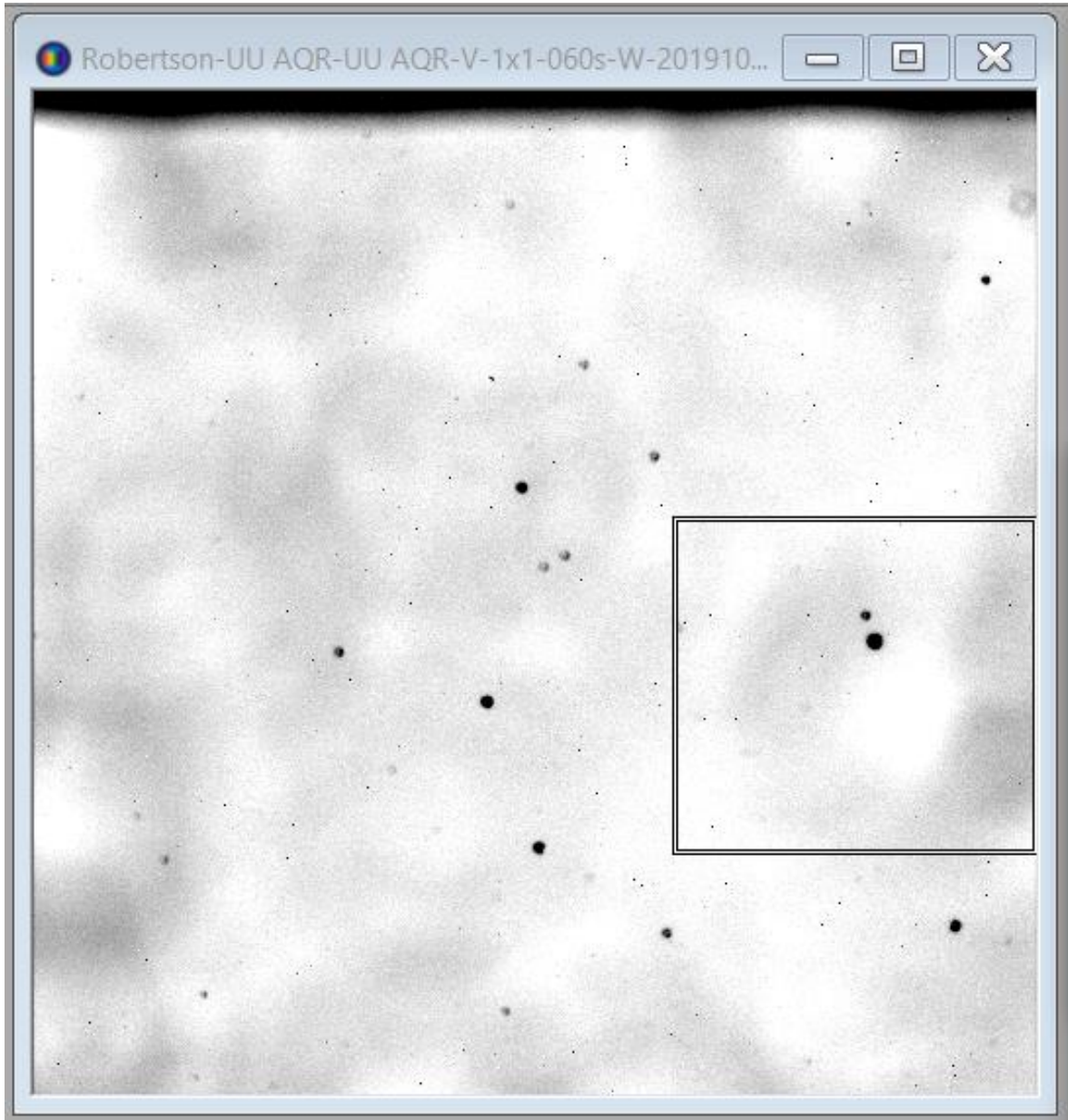
Another example of identical images with an image visualization stretch that is quite different.

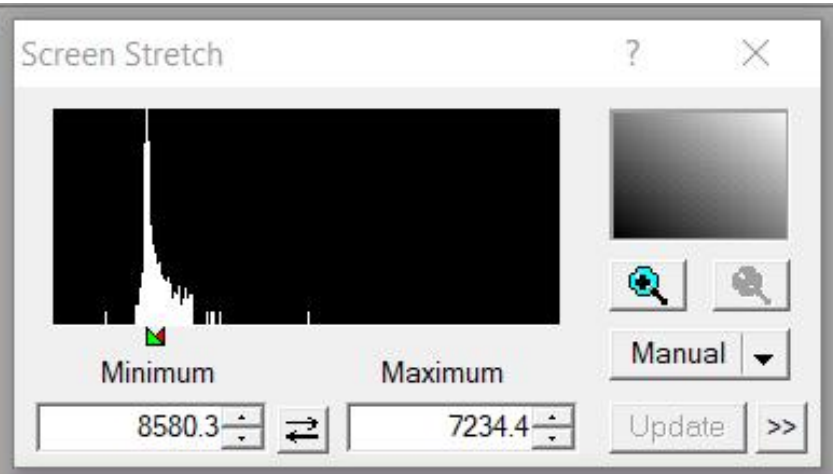


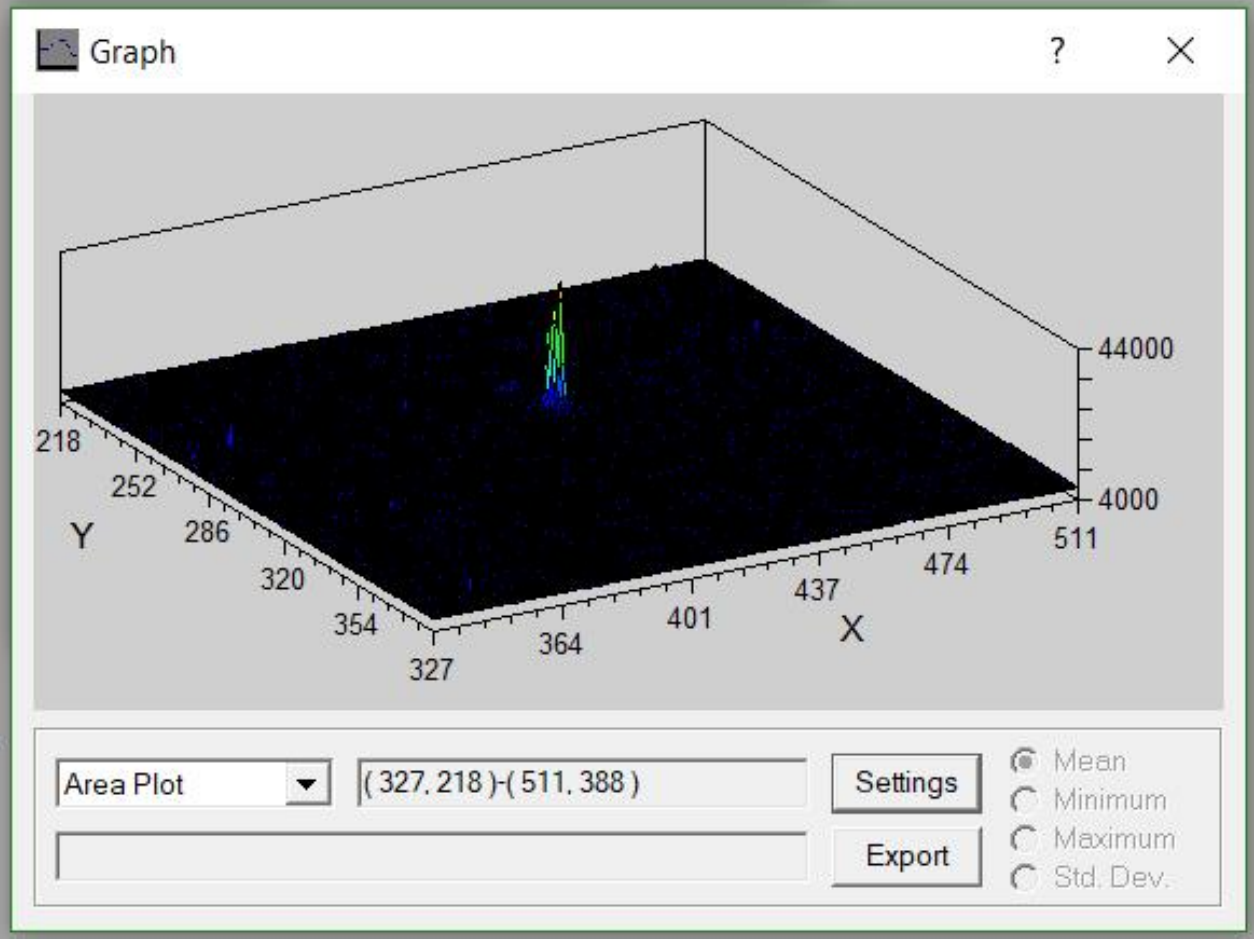




If images were like a forest, stars like trees, this image is stretched to look at the grass.







Same image, only no stretch, you can see the trees.

Be True To Your Data, Unless You Don't Need To

- Be aware that there is an enormous difference between

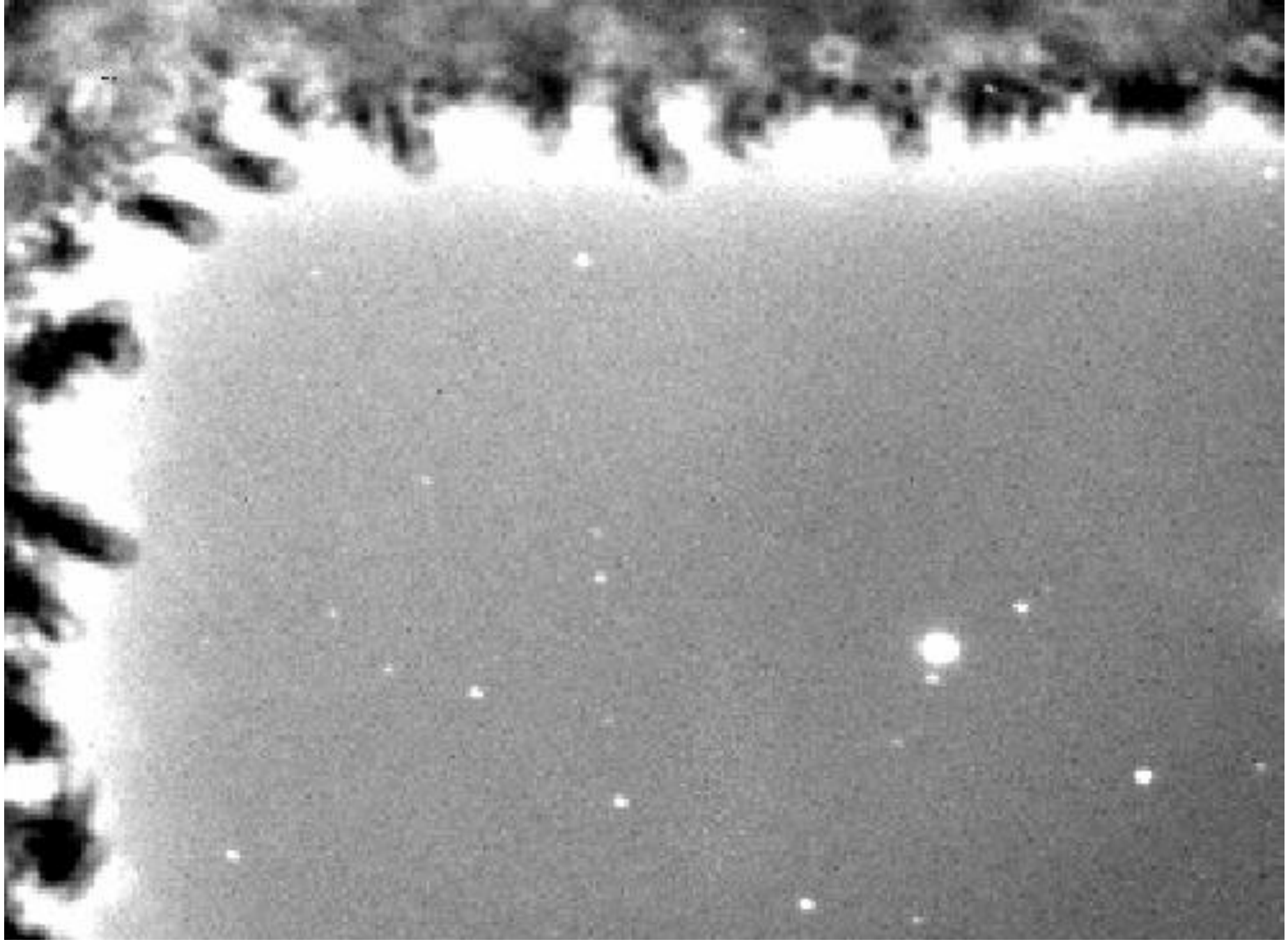
1. Image manipulations for creating scientific research data and performing photometry, astrometry, spectroscopy, etc.

2. Image manipulations for creating "pretty" pictures.

Certain image manipulations critically change the "data" and can yield spurious scientific results all the while being very beneficial in creating "ohh-ahhh" images for publication, Distribution, aspiration or inspiration.

M57

M39



Frost on the CCD window

THEM!

Full Well Capacity

- The total number of electrons that can accumulate in each individual pixel is referred to as the Well Depth or Capacity.

- Overexposure in a CCD occurs when more photoelectrons are created than can be stored in a pixel well, thereby exceeding the full well capacity (a.k.a. saturation).

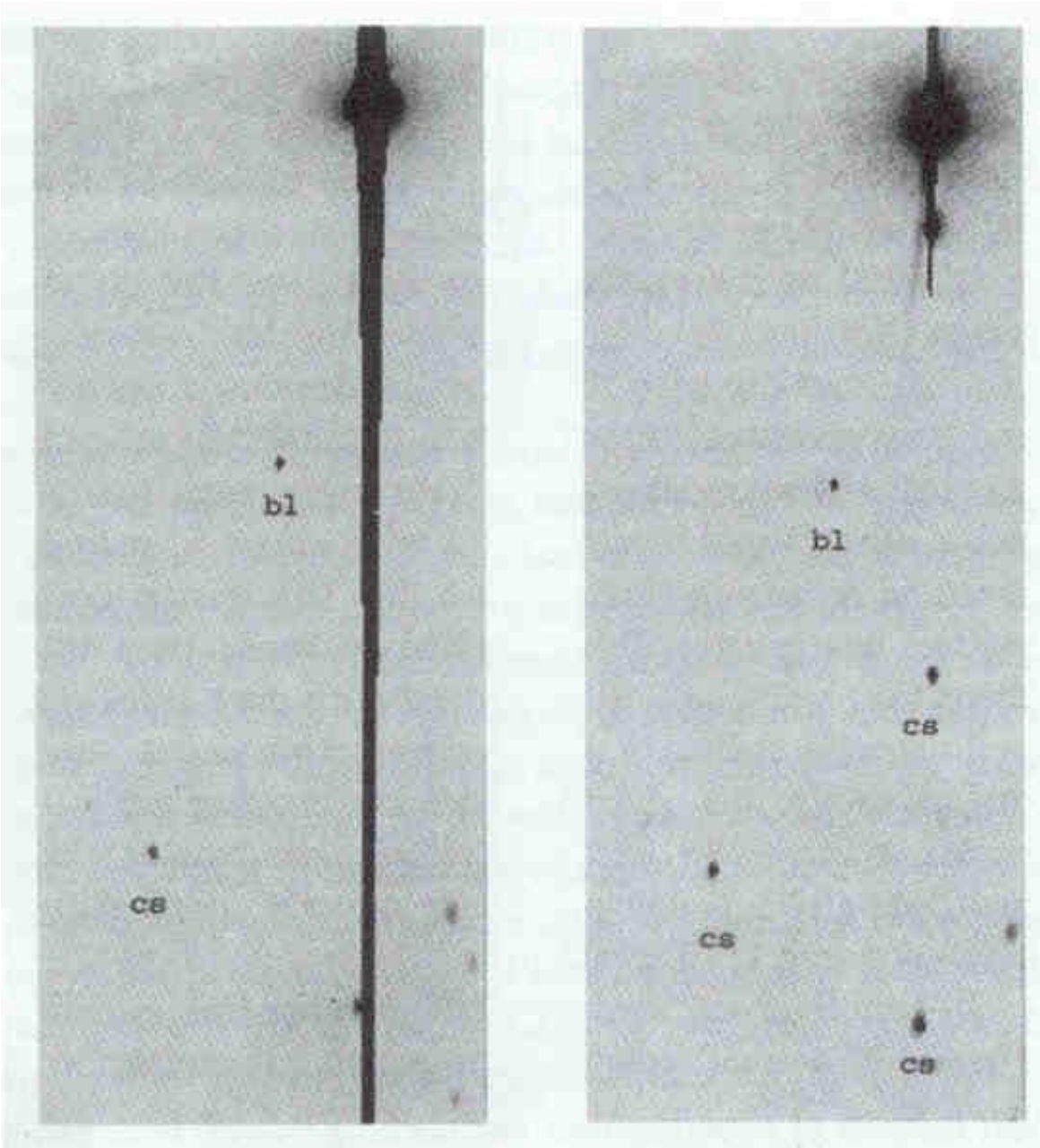
- Electrons can then overflow into adjacent pixels both during exposure integration and during readout (a.k.a. bleeding).

- Saturation and Bleeding is BAD. VERY VERY BAD! Avoid it like the PLAGUE!

Saturation & Bleeding

The effect of saturation on a CCD without anti-blooming architecture (left) and with anti-blooming architecture (right).

Saturated pixels spill over into other areas during integration and during readout along a CCD column.



Anti-blooming

- Accomplished with anti-blooming gates built into the CCD.
- Each individual pixel has an area (ditch) for “runoff”

- Advantages
  - pixels neighboring saturation are usable and there is no bleeding

- Disadvantages
  - saturated pixels are still unusable
  - 30% of the active pixel area is lost to the anti-blooming structures
  - effective reduction in quantum efficiency and spatial resolution
  - longer exposure times

Testing characteristics of a CCD

https://arxiv.org/ftp/arxiv/papers/1703/1703.04836.pdf

The Handbook for Astronomical Image Processing (by R. Berry and Jim Burnell, published by Willmann-Bell, Inc. at http://www.willbell.com) has devoted a chapter “Measuring CCD Performance”

Software for dealing with CCD FITS format images

CMUNIWIN http://c-munipack.sourceforge.net/ https://www.youtube.com/watch?v=yZJ0cqcHbLM

AstroImageJ https://www.astro.louisville.edu/software/astroimagej/

FITSview https://www.nrao.edu/software/fitsview/